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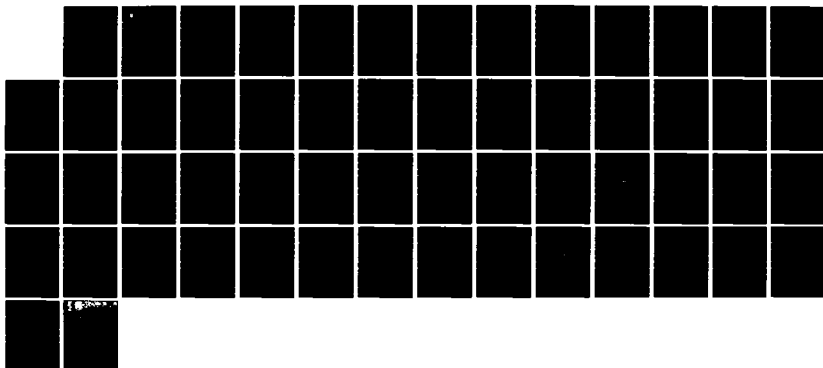
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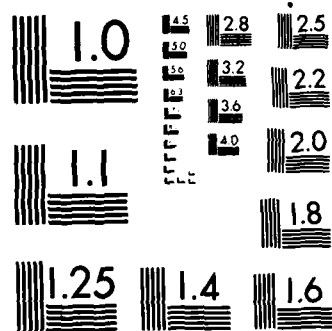
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USER'S MANUAL
FLAT PLATE PROGRAM

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Report 4508-4

Contract N00123-76-C-1371

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I. INTRODUCTION

In order to investigate the scattering effects associated with antennas in the presence of ship structures, the following Fortran IV computer code was developed for (NOSC) Naval Ocean Systems Center, San Diego, California. The computer code is used to compute the far zone scattered fields for antennas radiating in the near zone of structures made of flat plates. In its present form this code simulates a ship structure by a set of finite flat plates forming a convex structure for which the scattering from one flat plate to another is negligible. Using the present code, one can treat the structure by a single flat plate, a rectangular box, a rectangular pyramid, etc. This is the first of a generation of computer codes, and it is limited to the simpler scattering mechanisms. The final code after a three year study will allow one to model ship structures by arbitrarily placed finite flat plates and finite elliptic cylinders. This final model will allow for a simulation of ship structures in the presence of UHF and above antennas with all significant mutual interactions taken into account.

The present code is limited to one structure which can be simulated by as many as 14 plates. This is based on the array dimensions in the code and not a limitation of the theory. Each plate can consist of 6 corners; however, each corner must lie in a plane or the computer code will abort. The definition of the plates is made by first setting up a fixed cartesian coordinate system relative to the structure under investigation. The plates are, then, defined by the location of the corners. The antenna location is, also, specified in the same coordinate frame. One should note that the fixed coordinate system should be chosen such that one can easily define the structure. The program has the flexibility to handle arbitrary pattern cuts relative to this coordinate system as is discussed later.

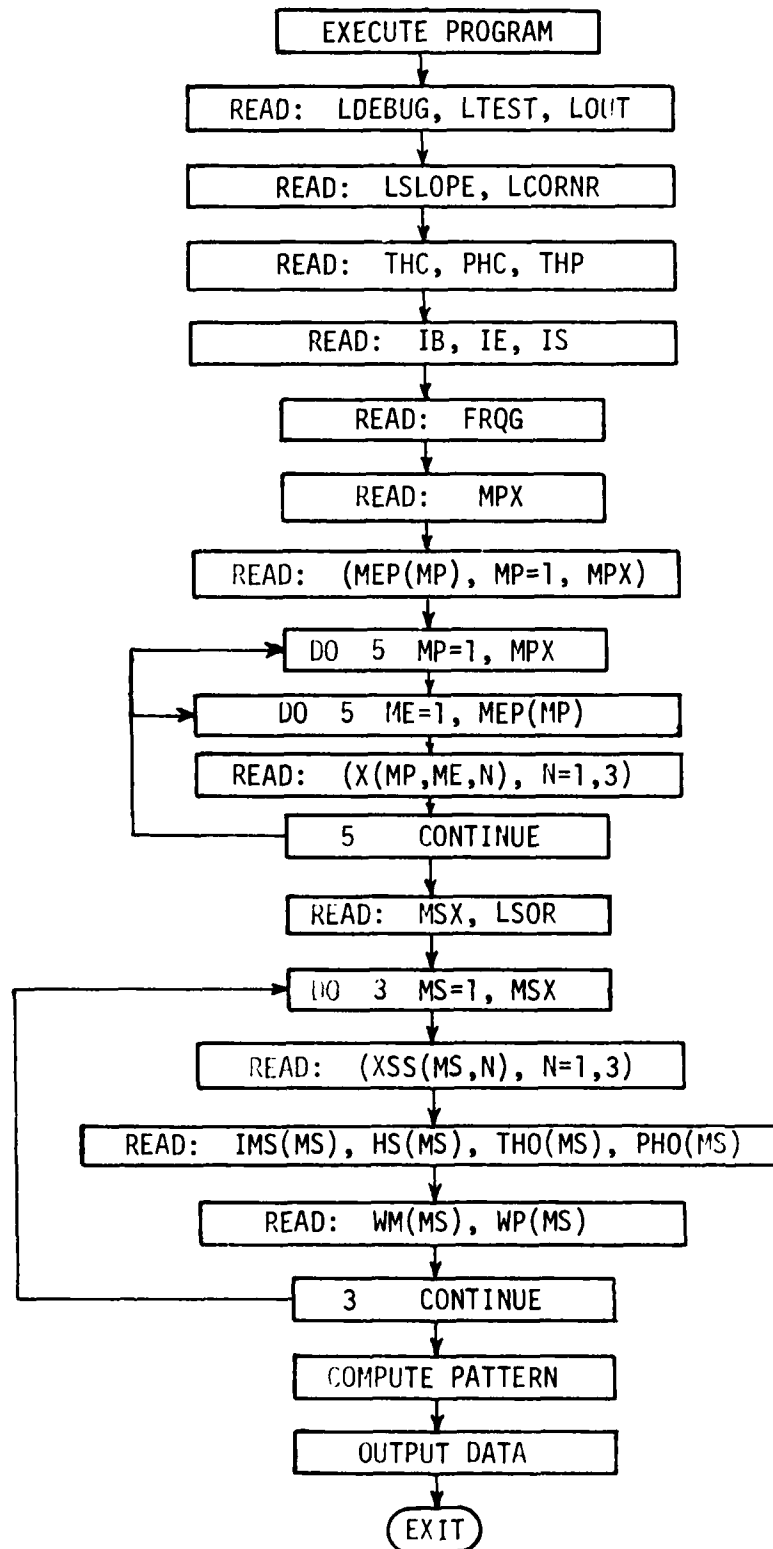
The antenna presently considered in the computer code is simulated by a set of electric or magnetic elemental radiators. There is a maximum of six such radiators which is limited by the computer code dimension and not the theory. Each electric or magnetic radiator has a cosine distribution, arbitrary length, arbitrary magnitude and phase, and arbitrary orientation. This elemental antenna is considered initially but can be easily modified in that the code is modular in construction. In this case, the SOURCE subroutines can be easily exchanged with another antenna pattern subroutine.

The present form of the computer code is not large in terms of computer storage and executes a pattern in short order. The storage is, of course, dependent on the dimensions which might vary; however, the present code requires approximately 100 K bytes. It will run a pattern cut of 360 points for a flat plate structure with one antenna in approximately 10 seconds on a CDC-6600 computer.

The limitations associated with the computer code results from the basic nature of the analysis. The solution is derived using the Geometrical Theory of Diffraction (GTD) technique which is a high frequency approach. In terms of the scattering from a finite flat plate, this means that each plate should have edges at least a wavelength long. In addition, antenna elements should not get closer than about a wavelength to any edge. In some cases, the previous wavelength limit can be reduced to a quarter wavelength.

The plot package necessary to generate the plots that are shown to illustrate the use of the code is not an integral part of the computer code. This results from the variations in basic plotting routines from one computer system to another. These variations make it presently impractical to write a general plot package to be used with the computer code. However, a polar plot routine is available for use with the code which in most cases can be easily modified to run on most computer systems.

TABLE I
BLOCK DIAGRAM OF THE INPUT DATA ORGANIZATION
FOR THE COMPUTER CODE



II. DEFINITION OF INPUT DATA

As stated earlier, the input data is defined relative to a fixed cartesian coordinate system which is selected by the user to make the definition of the structure as simple as possible. In this system, all linear dimensions are given in terms of inches and all angular dimensions in degrees. The angular quantities are expressed in terms of theta and phi, the usual spherical angles, defined relative to the operator's fixed coordinates.

It is felt that the maximum usefulness of the computer code can be achieved using it on an interactive computer system. As a consequence, all input data are defined in free format such that the operator need only put commas between the various inputs. This allows one on an interactive terminal to input data without being concerned with the fixed field length associated with a fixed format.

The organization of the input data is illustrated in Table 1. Note that all read statements are made on unit number 5, i.e., READ (5,-), where the "-" symbol refers to free format. In all the following discussions associated with logical variables a "T" will imply true, and an "F" will imply false. The complete words true and false need not be input in that most compilers just consider the first character in determining the state of the logical variable. The following list defines in detail the function associated with each of the input variables:

1. READ: LDEBUG, LTEST, LOUT

- a) LDEBUG: This is a logical variable defined by T or F. It is used to debug the program if errors are suspected within the program. If set true, the program prints out data on unit #6 associated with each of its internal operations. These data can, then, be compared with previous data which are known to be correct. It is, also, used to insure initial operation of the code. Only one pattern angle is considered. (normally set false)
- b) LTEST: This is a logical variable defined by T or F. It is used to test the input/output associated with each subroutine. The data written out on unit #6 are associated with the data in the window of the subroutine. They are written out each time the subroutine is called. It is, also, used to insure initial operation of the code. Only one pattern angle is considered. (normally set false)
- c) LOUT: This is a logical variable defined by T or F. It is used to output data on unit #6 associated with the main program. It too is used to initially insure proper operation. It can be used to examine the various components of the pattern. (normally set false)

2. READ: LSLOPE, LCORNR

- a) LSLOPE: This is a logical variable defined by T or F. It is used to tell the code whether or not slope diffraction is desired during the computation. (normally set true)
- b) LCORNR: This is a logical variable defined by T or F. It is used to tell the code whether or not corner diffraction is desired during the computation. (normally set true)

3. READ: THC, PHC, THP

This set of data is associated with the conical pattern desired during execution of the program. The pattern axis is defined by the spherical angles (THC, PHC) as illustrated in Figure 1. These angles define a radial vector direction which points in the direction of the

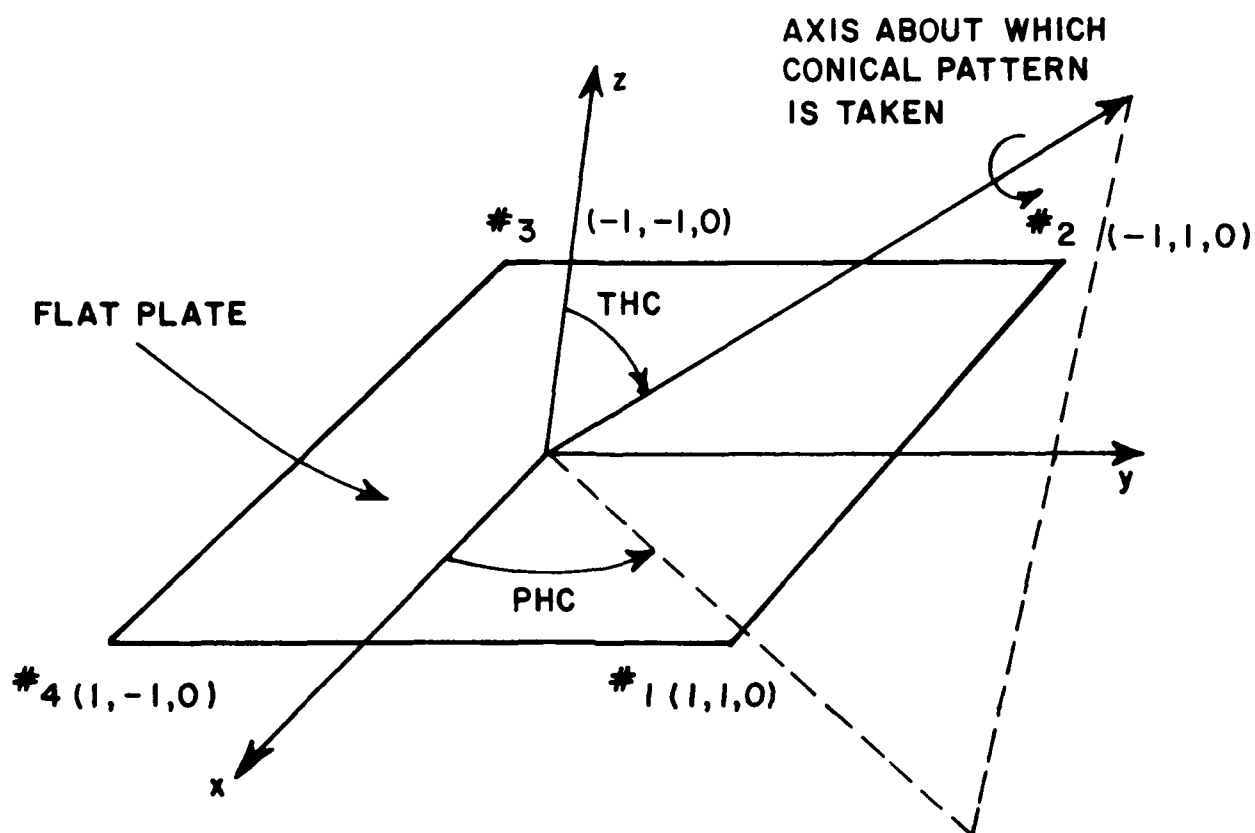


Figure 1. Definition of pattern axis.

pattern axis of rotation. These angles actually set-up a new coordinate system in relation to the original fixed coordinates. The new cartesian coordinates defined by the subscript "p" are found by first rotating about the z-axis the angle PHC and, then, about the y-axis the angle THC. The pattern is, then, taken in the "p" coordinate system in terms of spherical angles. The theta angle of the pattern taken about the z_p -axis is defined by THP. The phi angle is defined by the next read statement. In the present form the program will, then, compute any conical pattern in that THP is used as the conical pattern angle about the z_p -axis for the complete pattern calculation.

- a) THC, PHC: These are real variables. They are input in degrees and define the axis of rotation about which a conical pattern will be computed.
- b) THP: This is a real variable. It is input in degrees and used to define the conical angle about the axis of rotation for the desired pattern.

4. READ: IB, IE, IS

- a) IB, IE, IS: These are integer variables used to define angles in degrees. They are, respectively, the beginning, ending, and incremental values of the phi pattern angle.

As a result of the input given by the two previous read statements, the operator has completely defined the desired conical pattern to be computed during execution of the program.

5. READ: FRQG

- a) FRQG: This is a real variable which is used to define the frequency in gigahertz.

6. READ: MPX

- a) MPX: This is an integer variable which defines the maximum number of plates to be used in the present simulation of the structure. Presently, $1 \leq MPX \leq 14$.

7. READ: (MEP(MP), MP=1, MPX)

- a) MEP (MP): This is a dimensioned integer variable. It is used to define the number of corners (or edges) on the MP^{th} plate. They are defined on the same data line with commas between integer values. Presently, $1 \leq MEP (MP) \leq 6$ with $1 \leq MP \leq 14$.

8. READ: (X(MP,ME,N), N=1,3)

As stated earlier the locations of the corners of the flat plates are input in terms of the x, y, z coordinates in the fixed cartesian coordinate system.

- a) X(MP,ME,N): This is a triply dimensioned real variable. It is used to specify the location of the MEth corner of the MPth plate in inches. It is input on a single line with the real numbers being the x,y,z coordinates of the corner which correspond to N=1,2,3, respectively, in the array. For example, the array will contain the following for plate #1 and corner #2 located at x=2., y=4., z=6.:

X(1,2,1) = 2.
X(1,2,2) = 4.
X(1,2,3) = 6.

This data is input as: 2., 4., 6.

Considering the flat plate structure given in Figure 1, the input data is given by

1., 1., 0.	: corner #1	} plate #1
-1., 1., 0.	: corner #2	
-1., -1., 0.	: corner #3	
1., -1., 0.	: corner #4	

Presently: $1 \leq MP \leq 14$
 $1 \leq ME \leq 6$
 $1 \leq N \leq 3$

(See Section III for further details on defining the corner points.)

9. READ: MSX, LSOR

- a) MSX: This is an integer variable which defines the maximum number of elemental radiators to be considered during execution of the program. Presently, $1 \leq MSX \leq 6$.
- b) LSOR: This is a logical variable which is defined by T or F. It is used to specify whether or not the operator wants simply the antenna pattern alone without the scattering by the plate structure.

10. READ: (XSS (MS,N), N=1,3)

- a) XSS (MS,N): This is a doubly dimensioned real array which is used to define the x,y,z location of the MSth elemental radiator in the fixed cartesian coordinate system. Again, a single line of data contains the x,y,z (N=1,2,3) locations. Presently, $1 \leq MS \leq 6$
 $1 \leq N \leq 3$

(See Section III for further details on defining the source point.)

11. READ: IMS(MS), HS (MS), THO (MS), PHO (MS)

- a) IMS (MS): This is an integer array which is used to define whether the MSth source is an electric or magnetic elemental radiator.
IMS (MS) = 0 \Rightarrow electric
IMS (MS) = 1 \Rightarrow magnetic.
- b) HS (MS): This is a real array which is used to input the length of the MSth element in electrical wavelengths. It is not input in inches.
- c) THO (MS), PHO (MS): These are real arrays which are used to define the orientation of the MSth element in the fixed cartesian coordinate system. The THO, PHO angles are in degrees and define a radial direction which is parallel to the MSth element current flow. Again, THO is the theta angle and PHO is the phi angle in a normalspherical coordinate system. Presently, $1 \leq MS \leq 6$.

12: READ: WM (MS), WP (MS)

- a) WM (MS), WP (MS): These are real dimensioned arrays used to define the excitation associated with the MSth element. The magnitude is given by WM and the phase in degrees by WP. Presently, $1 \leq MS \leq 6$.

This concludes the definition of all the input parameters to the program. The program would, then, run the desired data and output the results on unit #6. However as with any sophisticated program, the definition of the input data is not sufficient for one to fully understand the operation of the code. In order to overcome this difficulty the next section discusses how the input data are interpreted and used in the program.

III. INTERPRETATION OF INPUT DATA

This computer code is written to require a minimum amount of user information such that the burden associated with a complex geometry will be organized internal to the computer code. For example, the operator need not instruct the code that two plates are attached to form a convex structure. The code flags this situation by recognizing that two plates have a common set of corners (i.e., a common edge). So if the operator wishes to attach two plates together he needs only define the two plates as though they were isolated. However, the two plates will have two identical corners. All the geometry information associated with plates with common edges is then generated by the code. As discussed below the computer code has two subtle interpretations which must be kept in mind while defining the geometry. The first subtlety is associated with simulating convex structures in which two or more plates are used in the computation. This problem results in that each plate has two sides. If the plates are used to simulate a closed or semi-closed structure, then possibly only one side of the plate will be illuminated by the antenna. Consequently, the operator must define the data in such a way that the code can infer which side of the plate is illuminated by the antenna. This is accomplished by defining the plate according to the right-hand rule. As one's fingers of the right hand follow the edges of the plate around in the order of their definition, his thumb should point toward the illuminated side of the plate. To illustrate this constraint associated with data format, let us consider the definition of a rectangular box. In this case, all the plates of the box must be specified such that they satisfy the right-hand rule with the thumb pointing outward as illustrated in Figure 2. If this rule were not satisfied for a given plate, then the code would assume that the antenna is within the box as far as the scattering from that plate is concerned.

The second situation which must be kept in mind is associated with antenna elements mounted on a plate. First, a plate-mounted antenna must be positioned close (approximately 10^{-6} wavelengths or less) but not exactly on the plate. If the antenna is positioned exactly on the plate, the code can not decide which side of the plate the antenna is mounted on for the calculation. For example, a monopole is mounted on one side of a plate; yet, the code must recognize which side. This point will be further discussed in the following section. There is another point associated with antennas mounted on perfectly conducting structures. If a plate-mounted monopole is considered in the computation, then one should input the equivalent dipole length and not the monopole length. The program automatically handles the half dipole modes associated with the monopole. Finally, if a plate-mounted slot antenna is considered in the computation, the code automatically doubles the radiation due to the image effect of the perfectly conducting ground plane.

The following section uses a set of sample problems to illustrate how the operator can realize the versatility of the code and still satisfy the few constraints associated with the input data format.

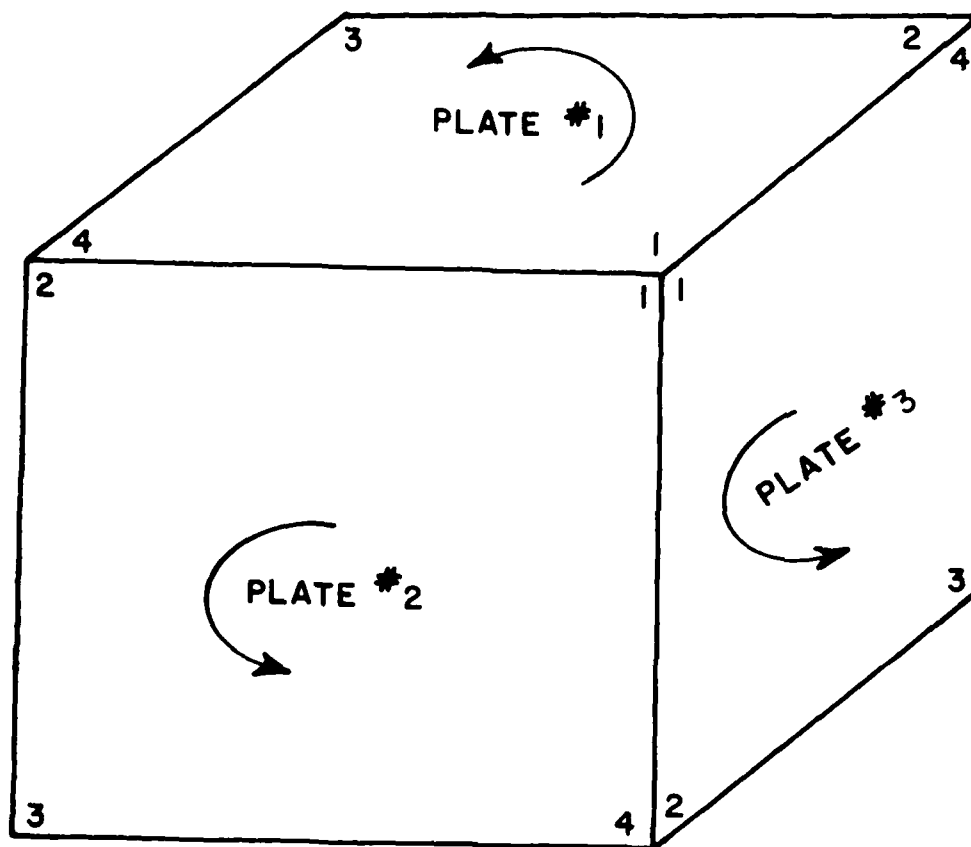


Figure 2. Data format used to define a box structure.

IV. APPLICATION OF CODE TO SEVERAL EXAMPLES

The following examples are used to illustrate the various features of the computer code. The results are presented in terms of polar plots which can be generated using the polar plot routine given in Appendix I. Note that the patterns are plotted in decibels with each division being 10 dB. The routine in Appendix I does not make any reference to a symbol subroutine, in that they are very much machine dependent. Thus, labeling is not included on the plots.

1. Consider the pattern of an electric dipole in the presence of a finite ground plane as shown in Figure 3. The input data is given by:

```
F,F,F
T,T
0.,0.,90.
0,360,1
10.43
1
4
0.,6.,6. : corner #1
0.,-6.,6. : corner #2
0.,-6.,-6. : corner #3
0.,6.,-6. : corner #4
} Plate #1
1,F
6.75,0.,0.
0.,1,0.,0.
1.,0.
```

The $E_{\theta p}$ pattern is plotted in Figure 4. The $E_{\phi p}$ pattern is not plotted in that it is of negligible value.

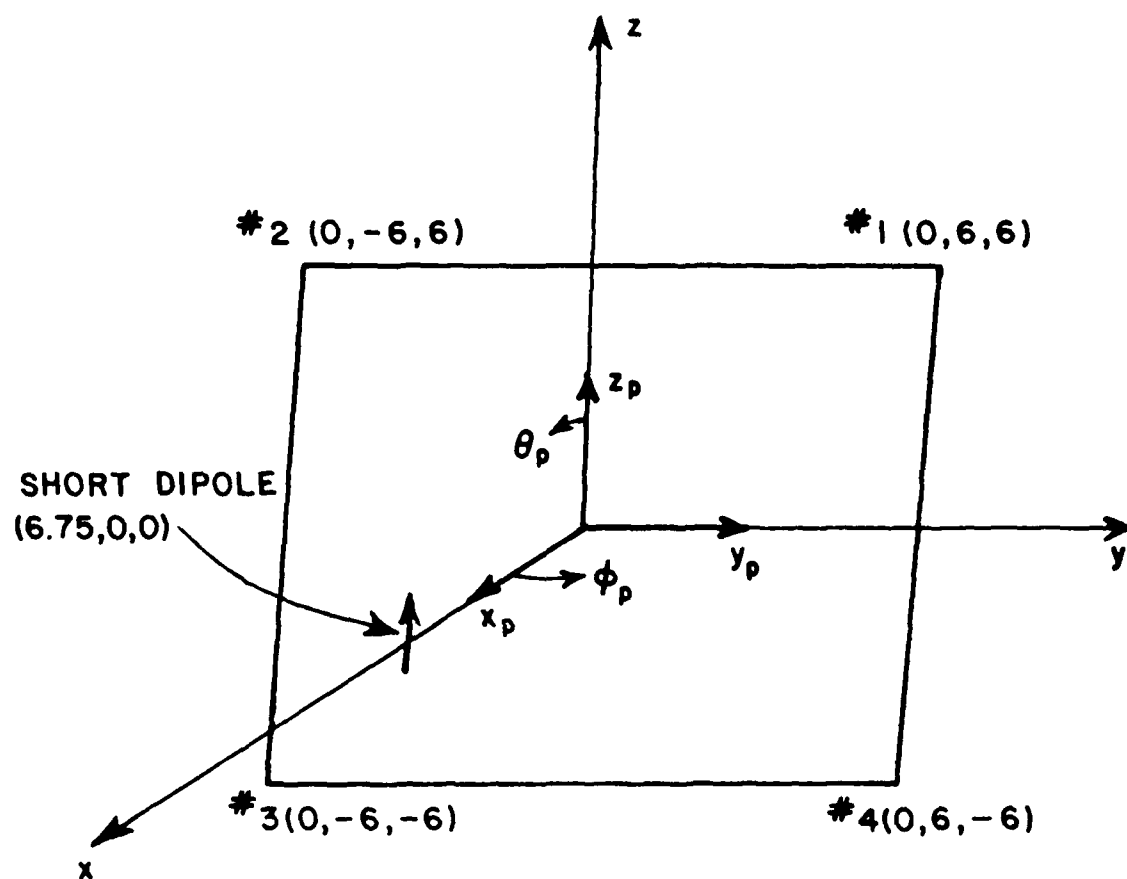


Figure 3. Short dipole in presence of a square ground plane.

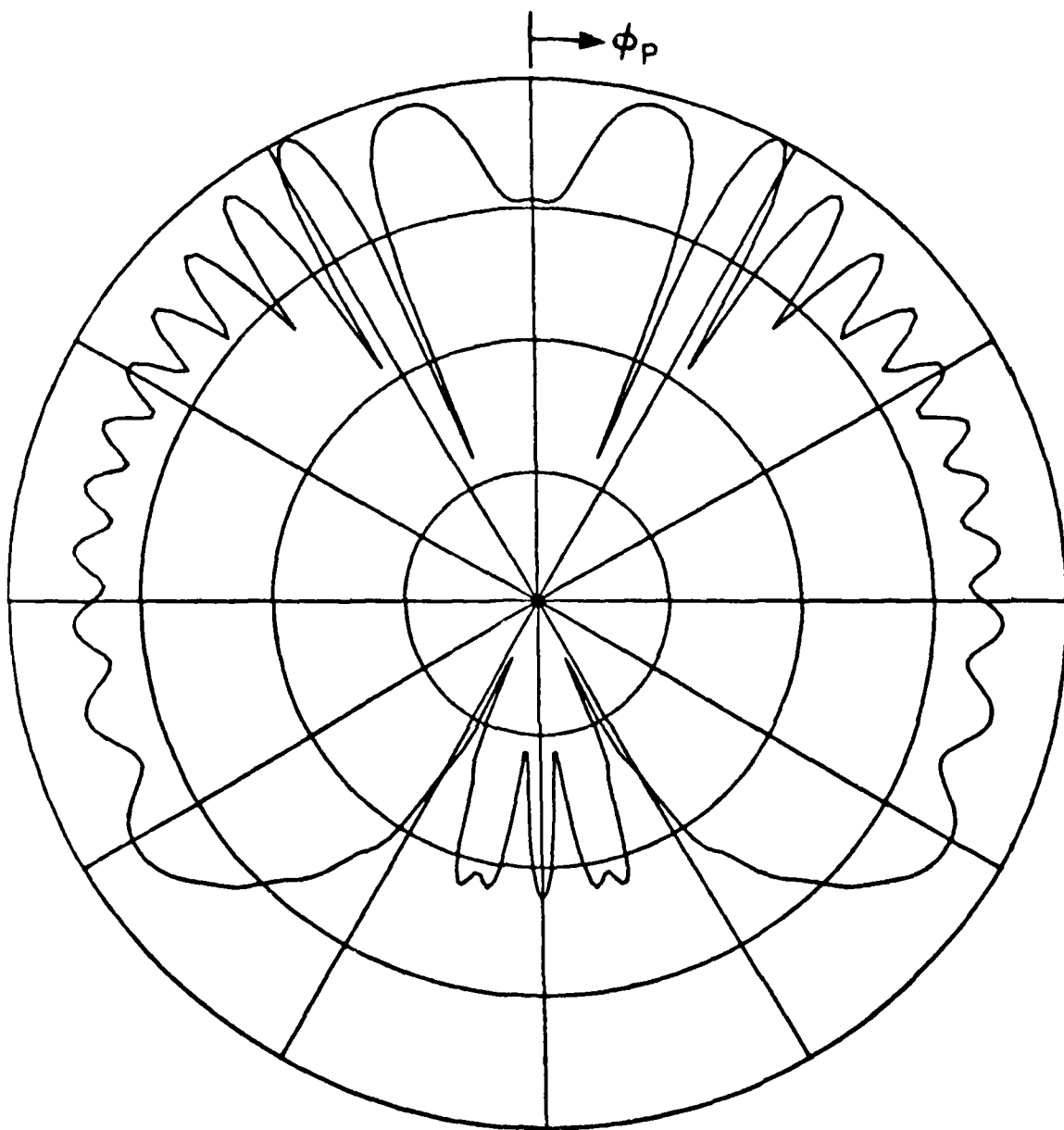


Figure 4. $E_{\theta p}$ radiation pattern for a short electric dipole located above a square plate at a frequency of 10.43 GHz.

2. Consider the pattern of a magnetic dipole in the presence of a finite ground plane as shown in Figure 3. The input data is given by:

F,F,F

T,T

0.,0.,90.

0,360,1

10.43

1

4

0.,6.,6.

0.,-6.,6.

0.,-6.,-6.

0.,6.,-6.

1,F

6.75,0.,0.

1,0.1,0.,0.

1.,0.

The $E_{\phi p}$ pattern is plotted in Figure 5. The $E_{\theta p}$ pattern is not plotted in that it is of negligible value.

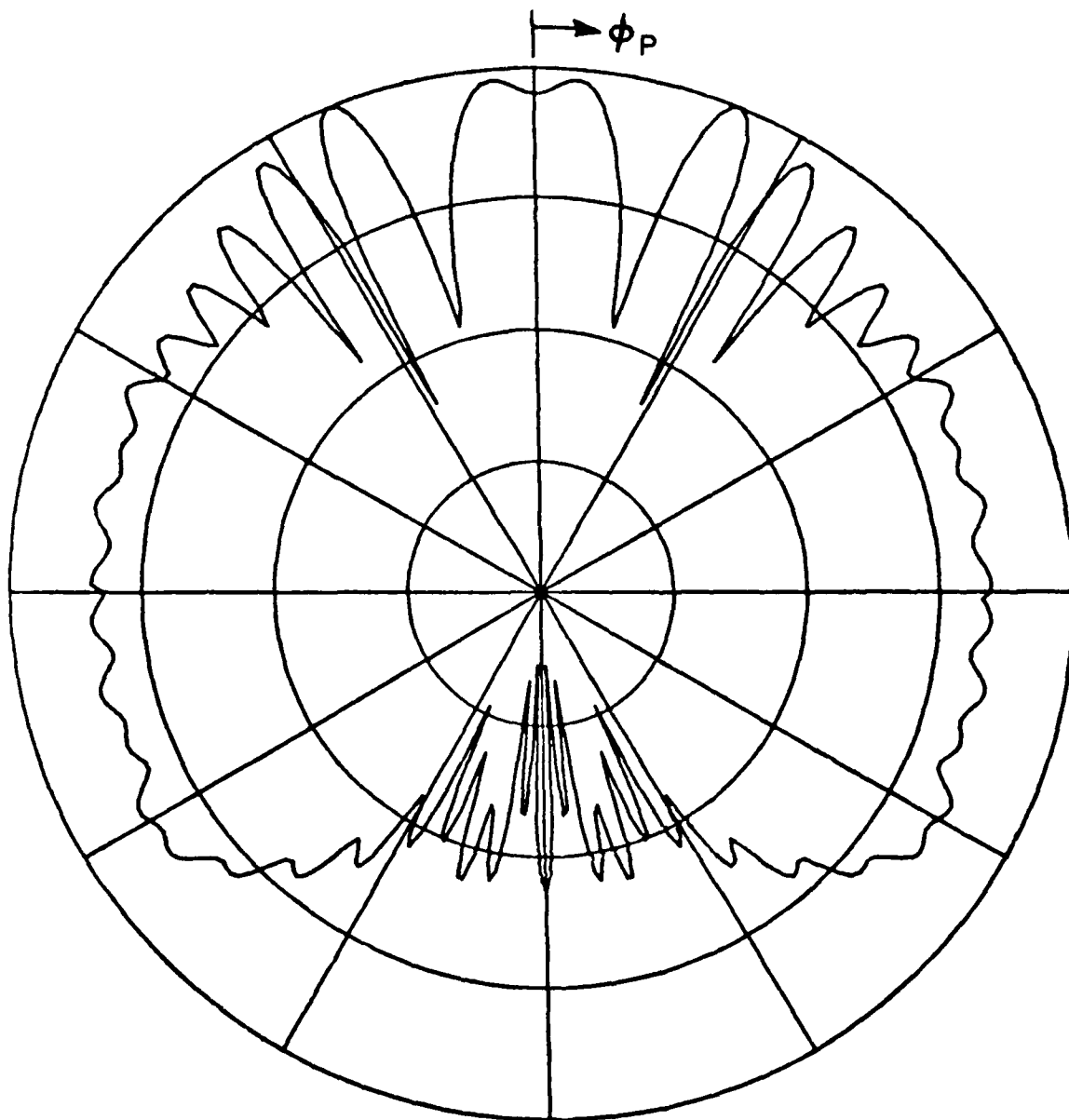


Figure 5. $E_{\phi P}$ radiation pattern for a short magnetic dipole located above a square plate at a frequency of 10.43 GHz.

3. Consider the H-plane pattern of an electric dipole in the presence of a roof-top type structure as shown in Figure 6. The input data is given by:

F,F,F		
T,T		
90.,0.,90.		
0.360,1		
4.		
2		
4,4		
6.496,0.,0.	: corner #1	} Plate #1
6.496,3.34,-3.34	: corner #2	
-6.496,3.34,-3.34	: corner #3	
-6.496,0.,0.	: corner #4	
6.496,0.,0.	: corner #1	} Plate #2
-6.496,0.,0.	: corner #2	
-6.496,-3.34,-3.34	: corner #3	
6.496,-3.34,-3.34	: corner #4	
1,F		
0.,0.,3.3		
0.,5,90.,0.		
1.,0.		

The $E_{\theta p}$ polar pattern is plotted in Figure 7. The same pattern is plotted in rectangular form in Figure 8 where it is compared with a measured pattern.

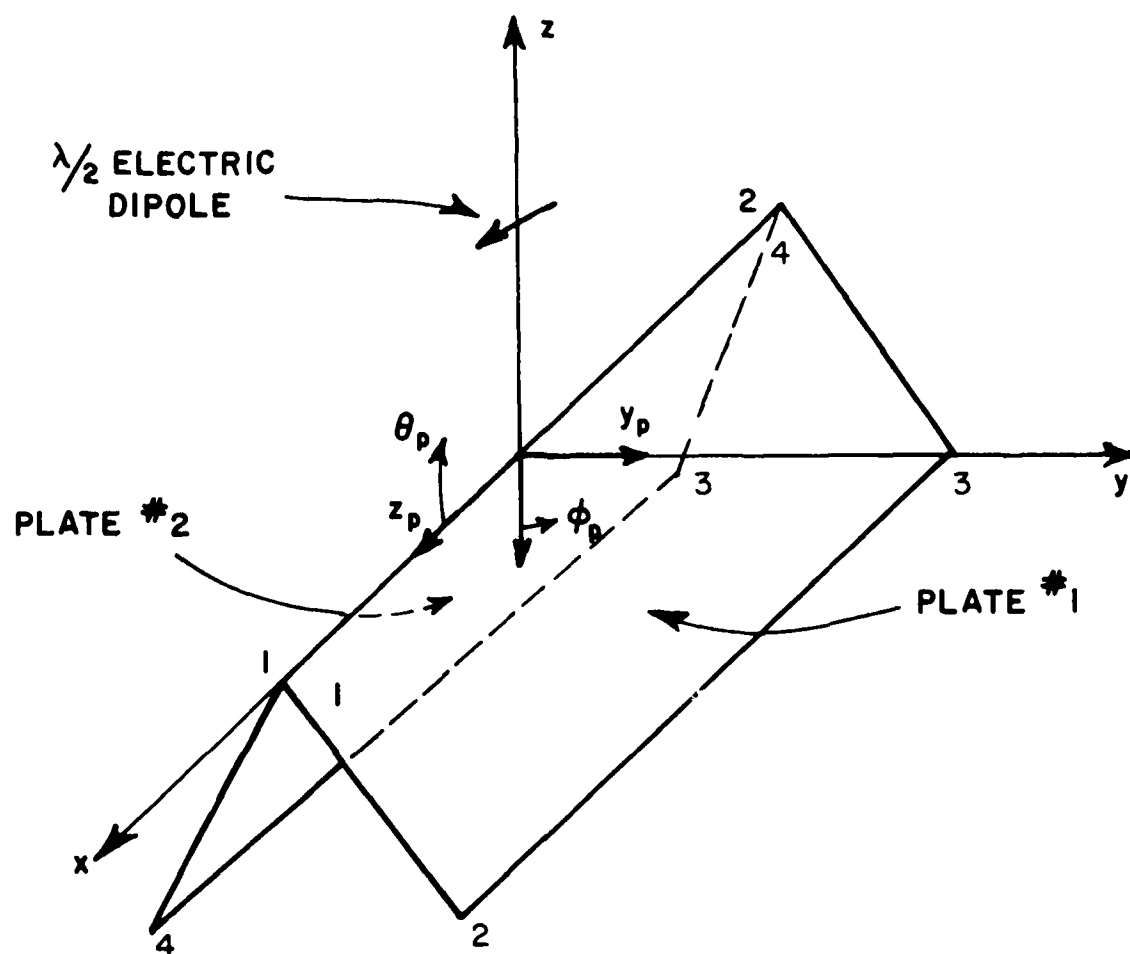


Figure 6. An electric dipole in the presence of a roof-top type structure used for H-plane pattern calculation.

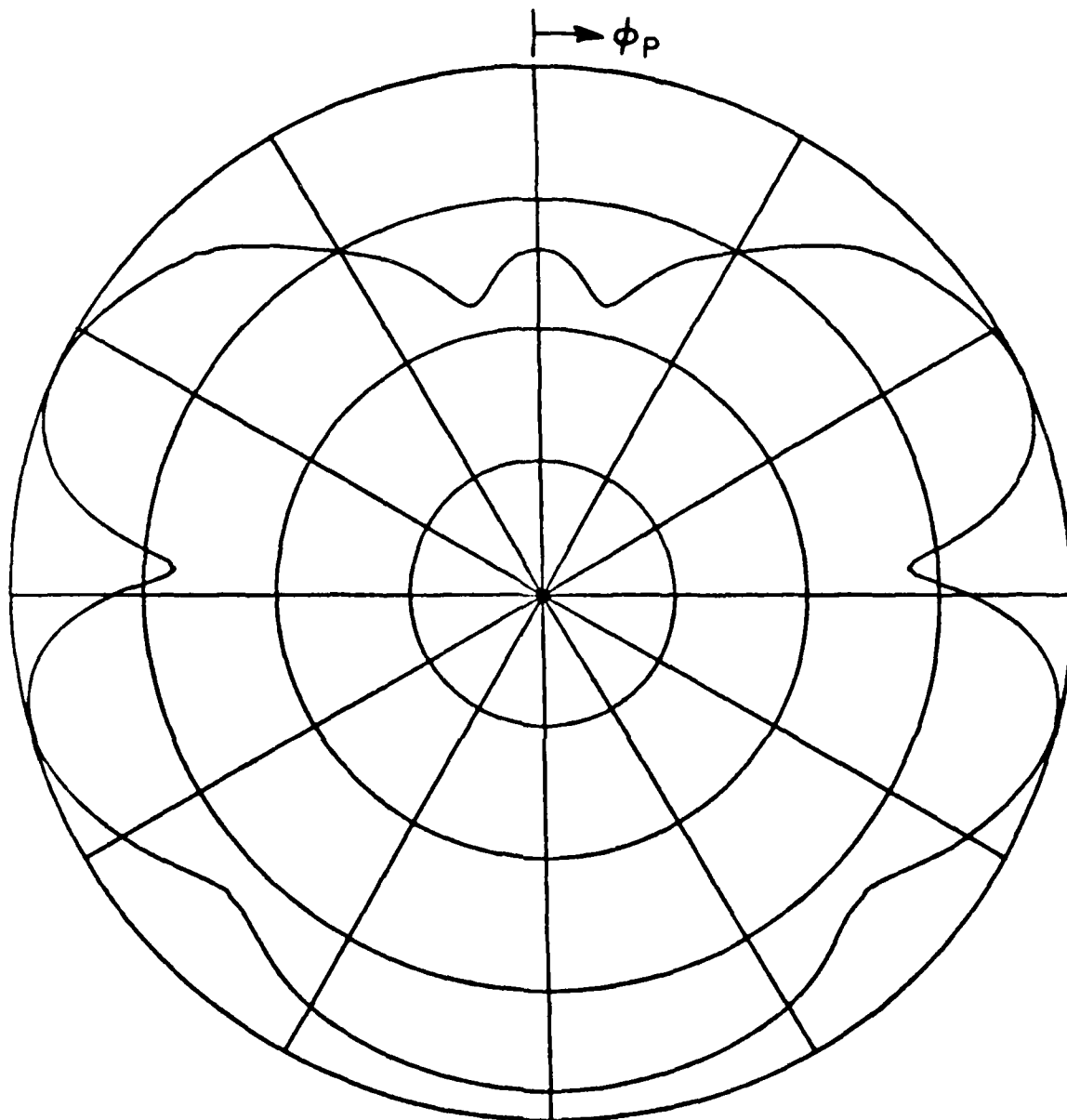


Figure 7. $E_{\theta p}$ radiation pattern for a $\lambda/2$ electric dipole located above a roof-top type structure at a frequency of 4 GHz.

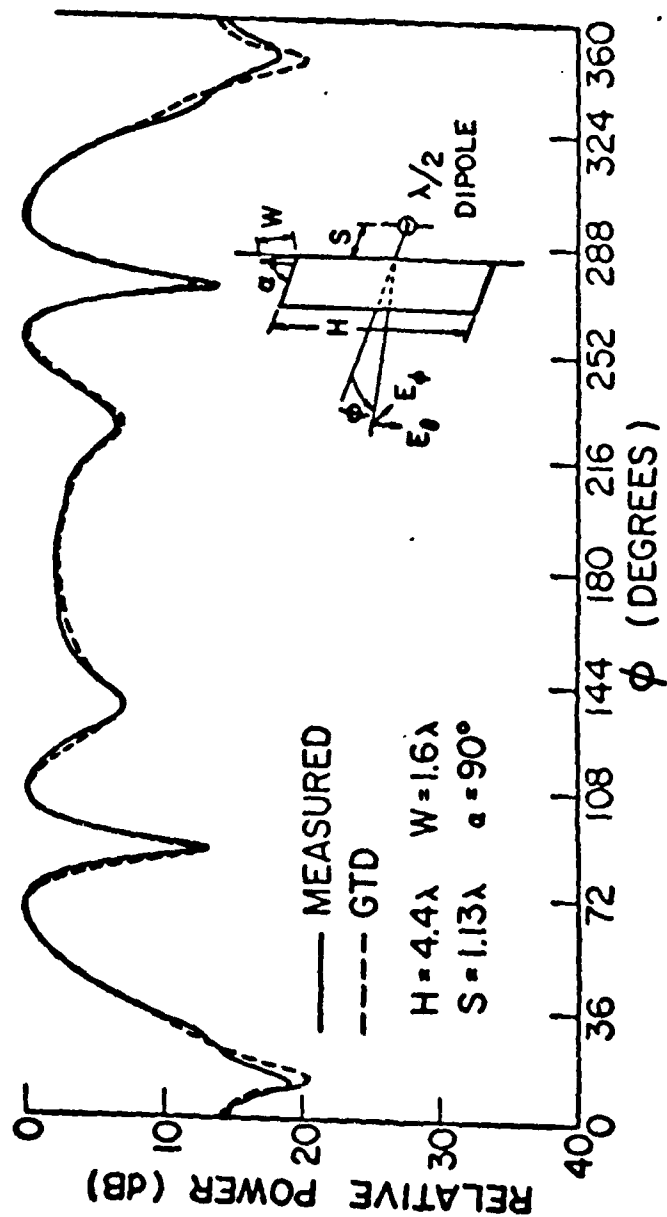


Figure 8. Comparison of the measured and calculated E_θ radiation pattern of a dipole near a roof-like structure in the indicated plane.

4. Consider an off-principal plane pattern of an electric dipole in the presence of a roof-top type structure as shown in Figure 9. The input data is given by:

F,F,F
T,T
30.,0.,90.
0,360,1
4.
2
4,4
6.496,0.,0.
6.496,3.34,-3.34
-6.496,3.34,-3.34
-6.496,0.,0.
6.496,0.,0.
-6.496,0.,0.
-6.496,-3.34,-3.34
6.496,-3.34,-3.34
1,F
0.,0.,3.3
0.,5,90.,0.
1.,0.

The $E_{\theta p}$ and $E_{\phi p}$ polar patterns are plotted in Figure 10. The same patterns are plotted in rectangular form in Figure 11 where they are compared with measured results.

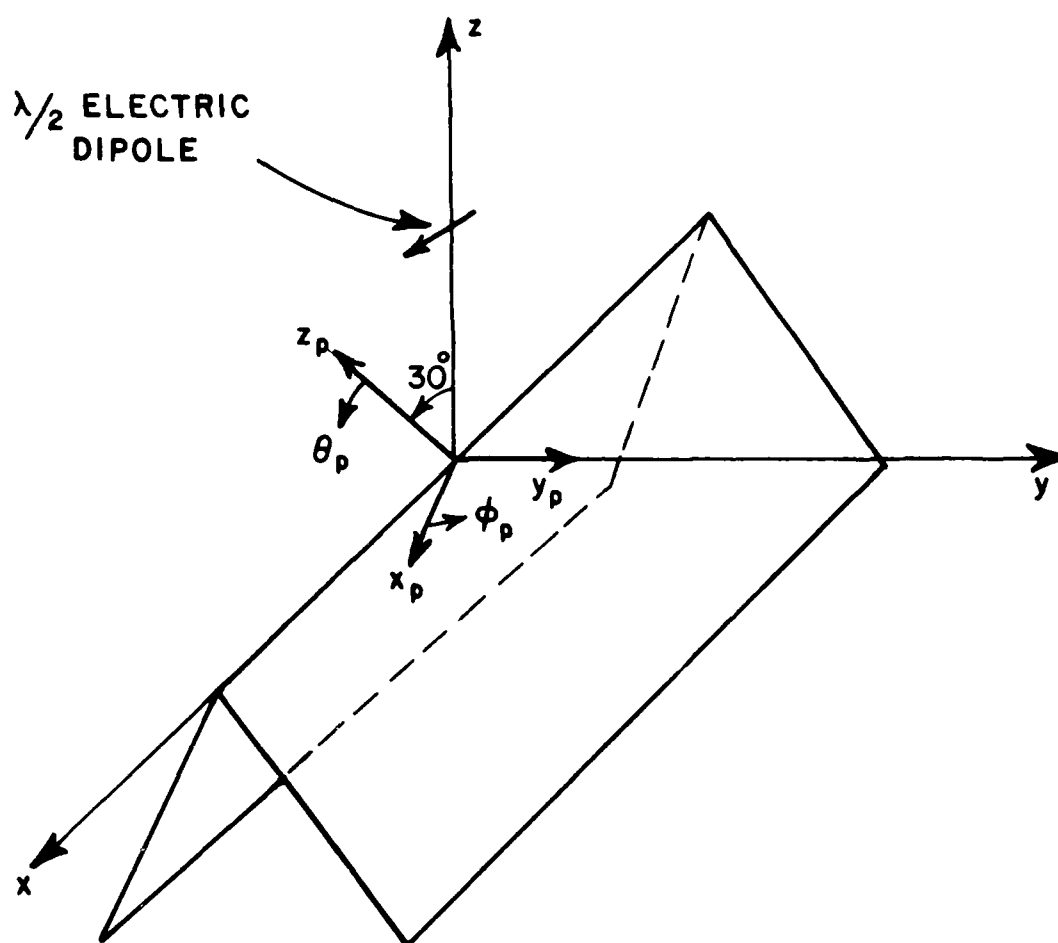


Figure 9. An electric dipole in the presence of a roof-top type structure used for off-principal plane pattern calculation.

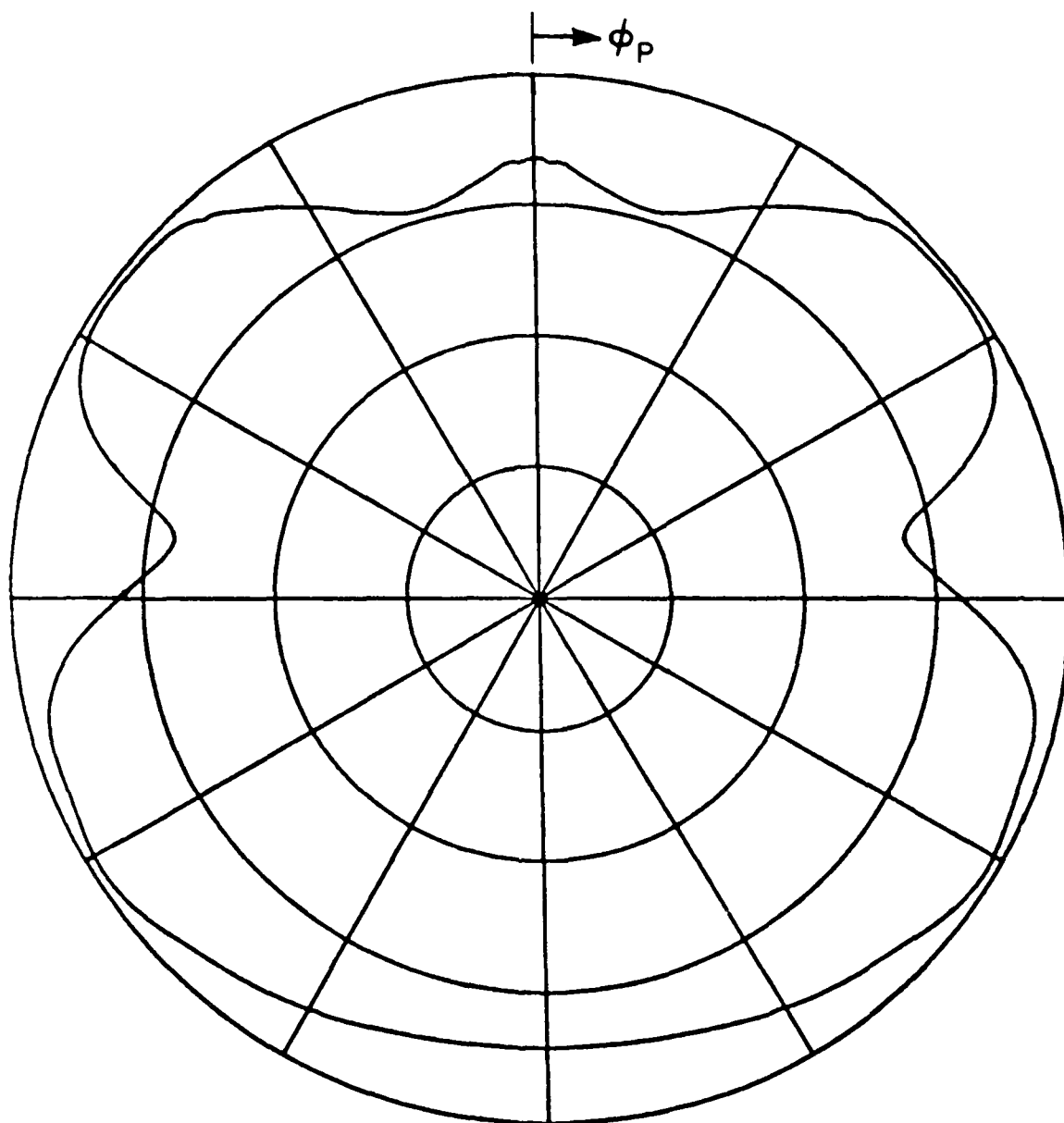


Figure 10a. $E_{\theta p}$ radiation pattern for a $\lambda/2$ electric dipole located above a roof-top type structure at a frequency of 4 GHz.

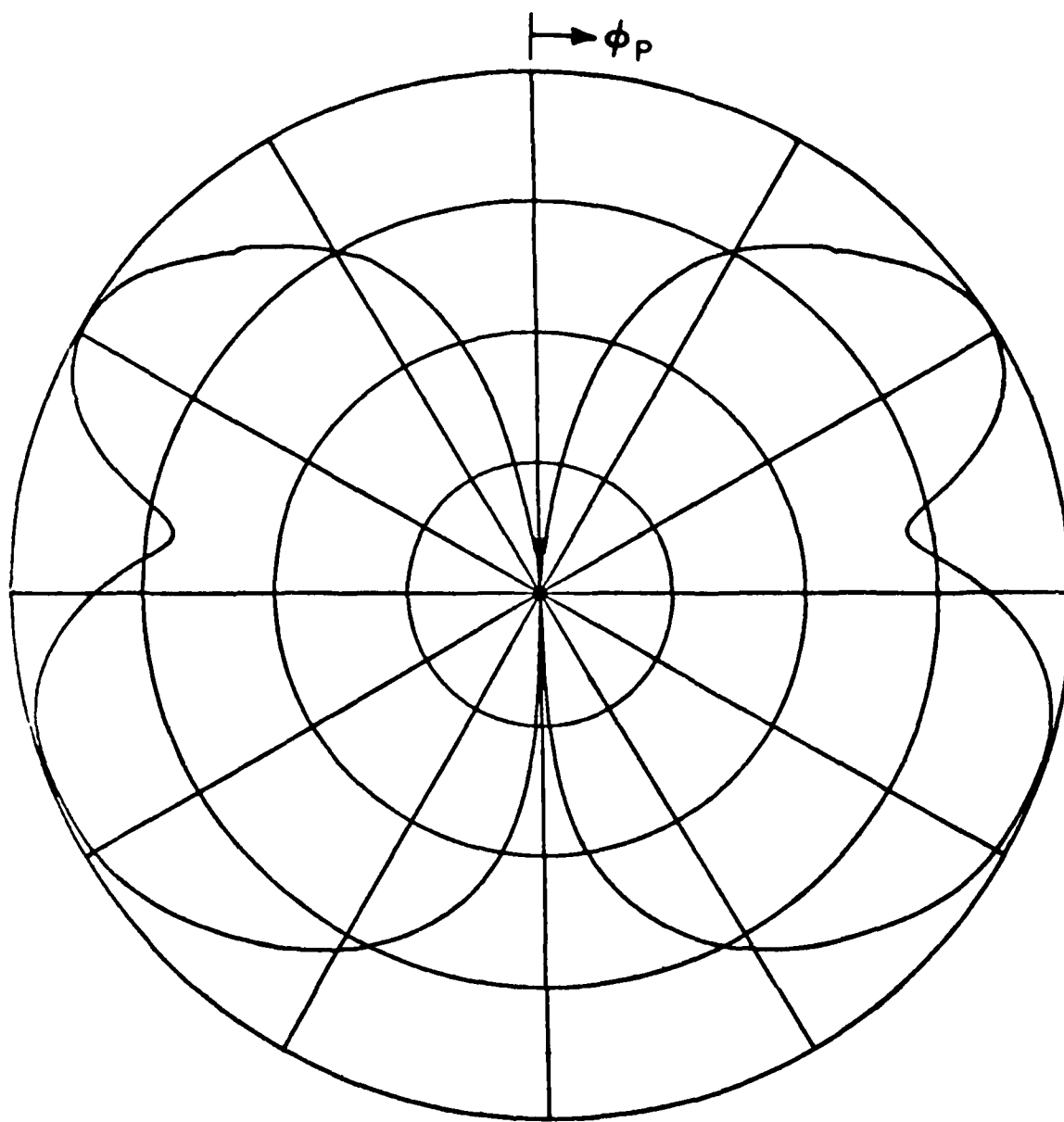
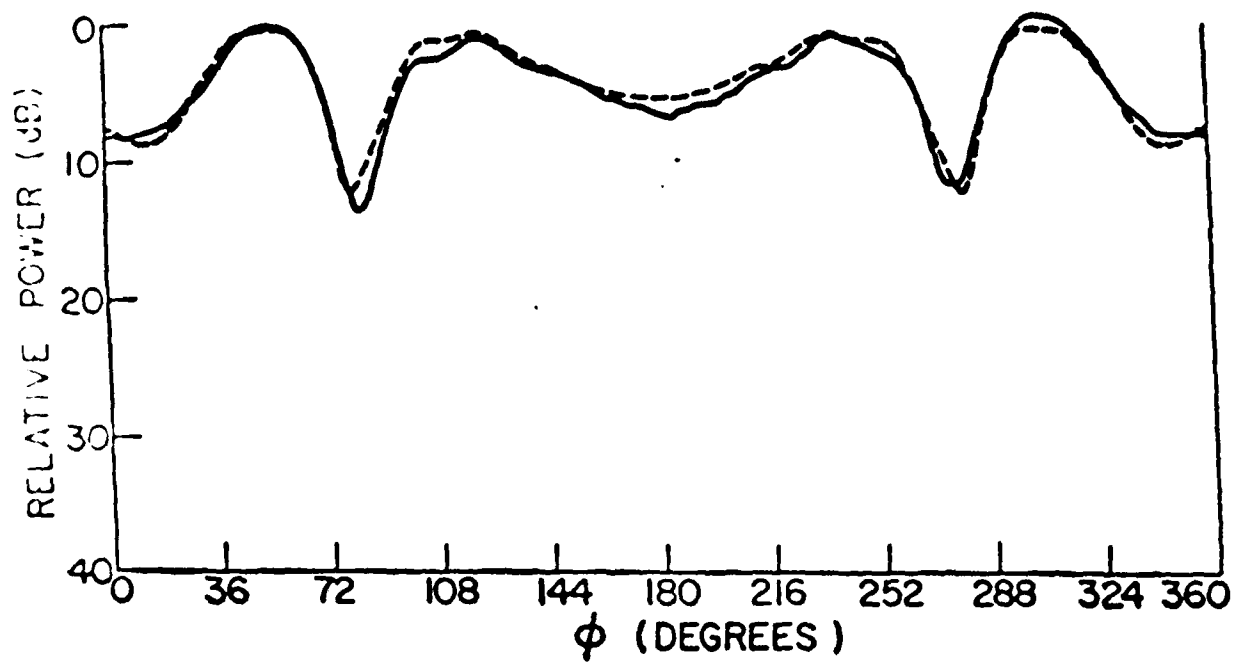
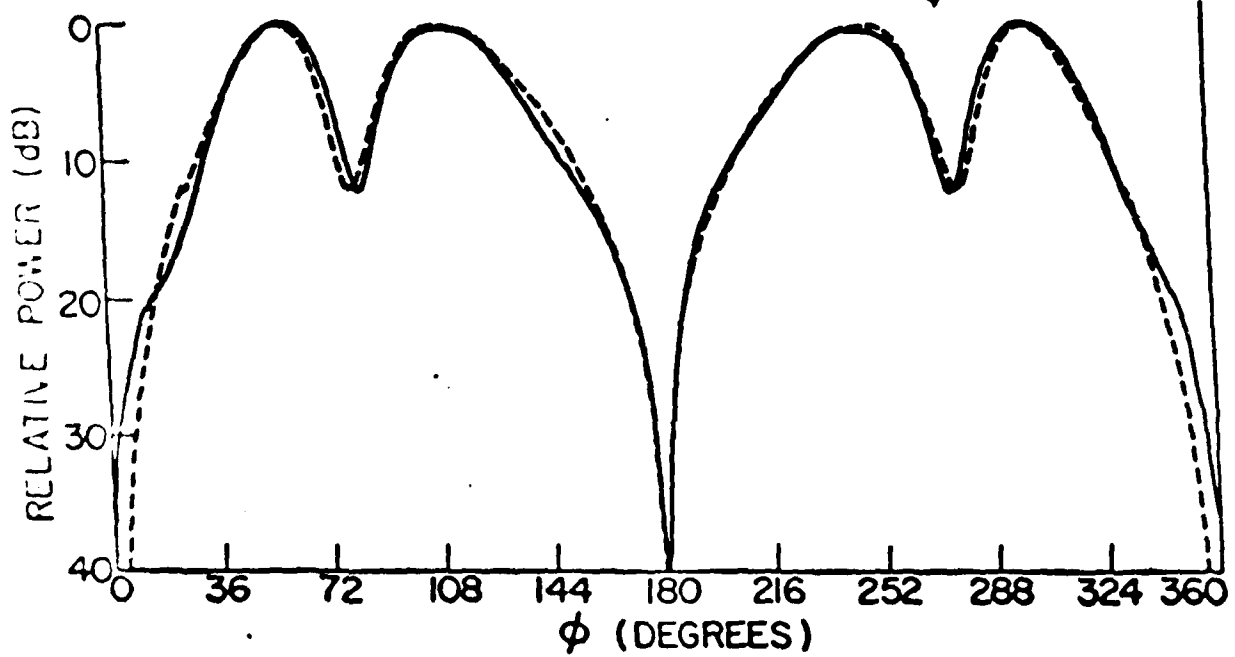
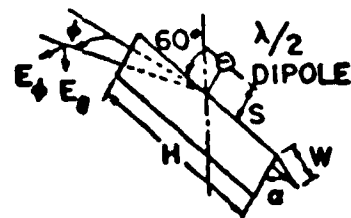


Figure 10b. $E_{\phi p}$ radiation pattern for a $\lambda/2$ electric dipole located above a roof-top type structure at a frequency of 4 GHz.



(a)

— MEASURED
 --- GTD
 $H = 4.4\lambda$ $W = 1.6\lambda$
 $S = 1.13\lambda$ $\alpha = 90^\circ$



(b)

Figure 11. Comparison of the measured and calculated radiation pattern for a) E_θ and b) E_ϕ polarizations.

5. Consider a principal plane pattern of an electric dipole in the presence of a pyramid structure as shown in Figure 12. The input data is given by:

F,F,F
T,T
90.,90.,90.
0,360,1
11.81
4
3,3,3,3
6.,0.,0.
0.,6.,-6.
-6.,0.,0.
-6.,0.,0.
0.,6.,-6.
0.,-6.,-6.
-6.,0.,0.
0.,-6.,-6.
6.,0.,0.
6.,0.,0.
0.,-6.,-6.
0.,6.,-6.
1,F
0.,0.,3.
0,0.5,90.,0.
1.,0.

The $E_{\phi p}$ pattern is plotted in Figure 13. The $E_{\theta p}$ pattern is not plotted in that it is of negligible value.

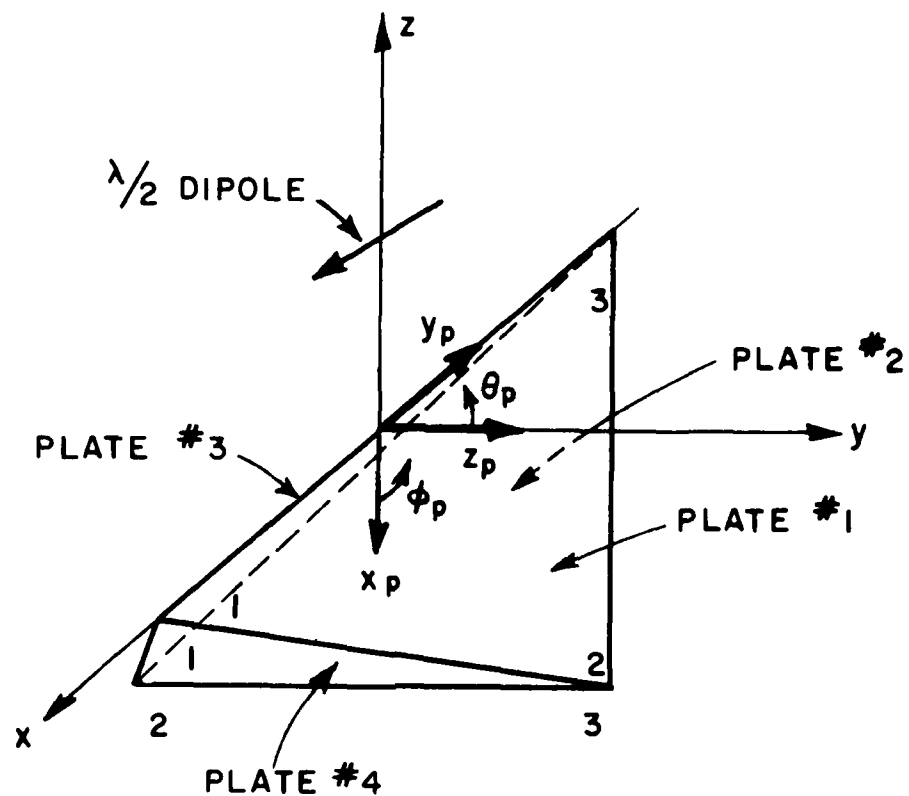


Figure 12. A $\lambda/2$ dipole in the presence of a pyramid structure.

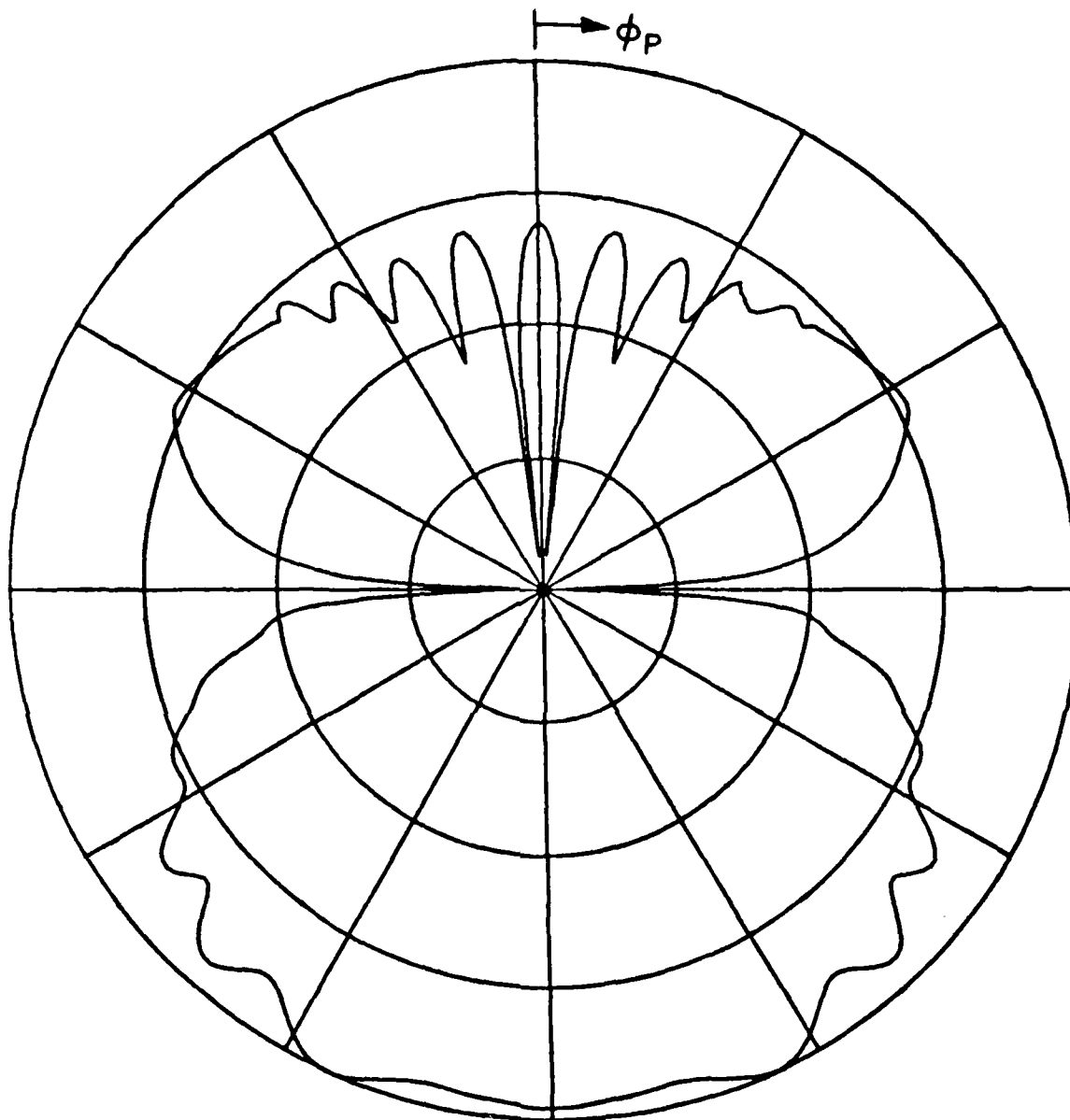


Figure 13. E_{ϕ_P} radiation pattern for a $\lambda/2$ electric dipole located above a pyramid at a frequency of 11.81 GHz.

6. Consider the pattern of a $\lambda/4$ monopole mounted in the center of a square ground plane as shown in Figure 14. The input data is given by:

F,F,F
T,T
90.,90.,90.
0,360,1
10.
1
4
6.,6.,0.
-6.,6.,0.
-6.,-6.,0.
6.,-6.,0.
1,F
0.,0.,1.E-10
0.,.5,0.,0.
1.,0.

The $E_{\phi p}$ pattern is plotted in Figure 15. The $E_{\theta p}$ pattern is not plotted in that it is of negligible value.

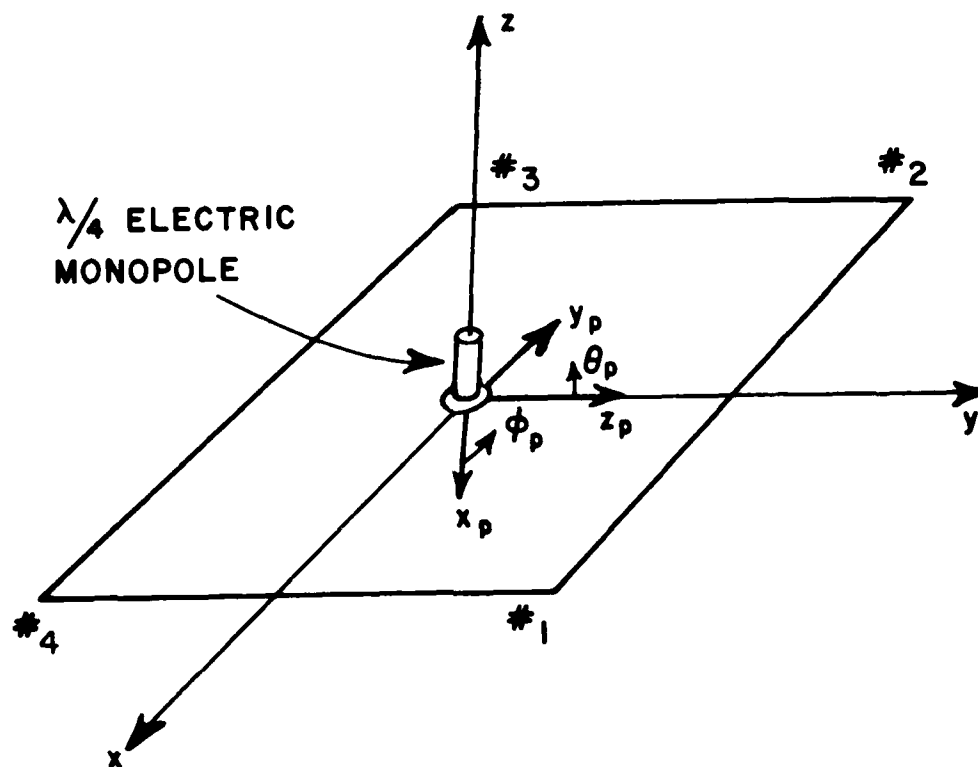


Figure 14. A $\lambda/4$ monopole mounted on a square ground plane.

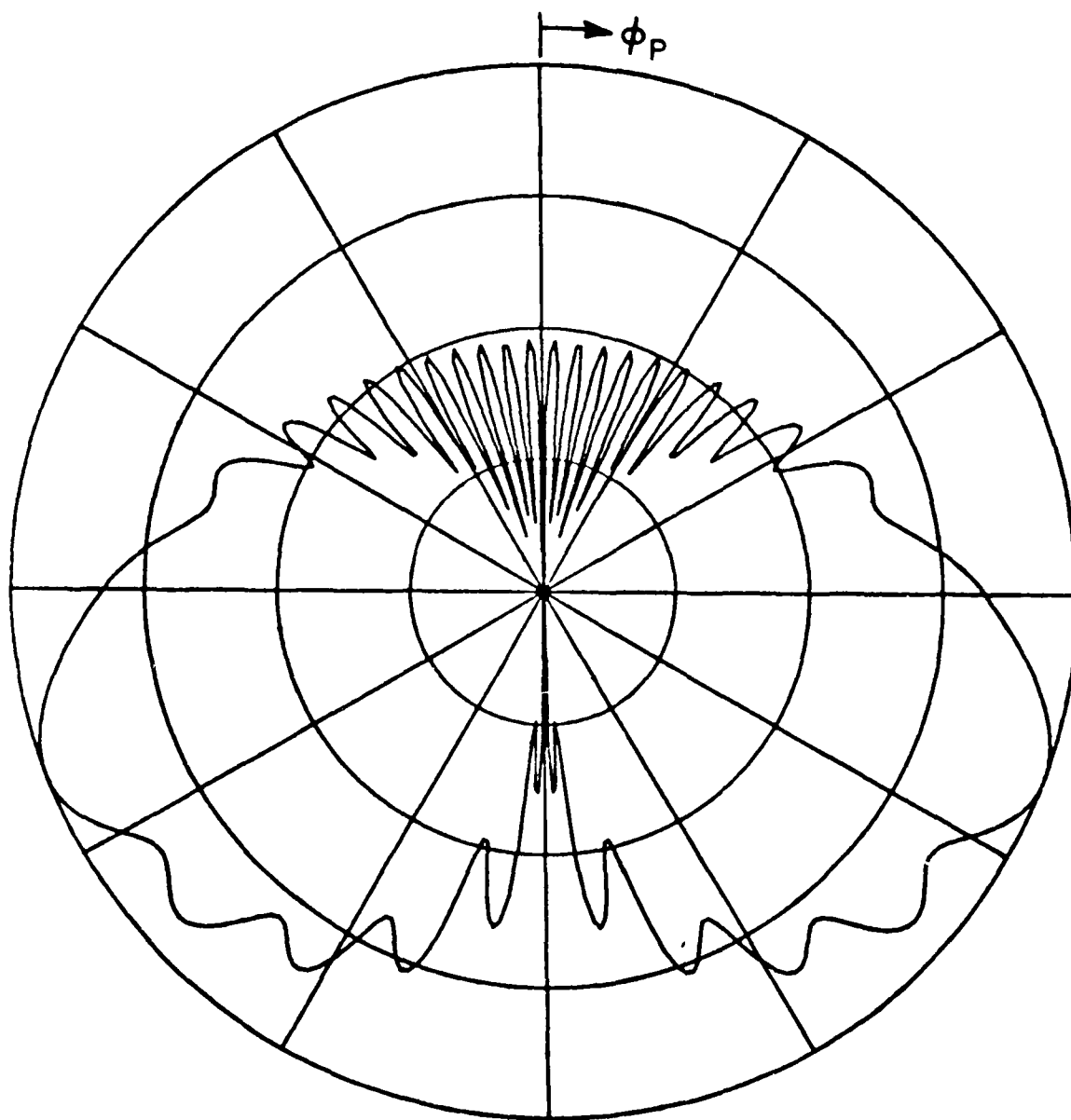


Figure 15. E_{ϕ_P} radiation pattern of a $\lambda/4$ electric monopole mounted in the center of a square plate at a frequency of 10 GHz.

7. Consider the pattern of a $\lambda/2$ slot antenna mounted in the center of a square ground plane as shown in Figure 16. The input data is given by:

F,F,F
T,T
90.,135.,90.
0,360,1
10.
1
4
6.,6.,0.
-6.,6.,0.
-6.,-6.,0.
6.,-6.,0.
1,F
0.,0.,1.E-10
1.,5,90.,90.
1.,0.

The $E_{\theta p}$ and $E_{\phi p}$ patterns are plotted in Figure 17. Note this pattern is taken directly across the corner of the plate; yet, both patterns are continuous.

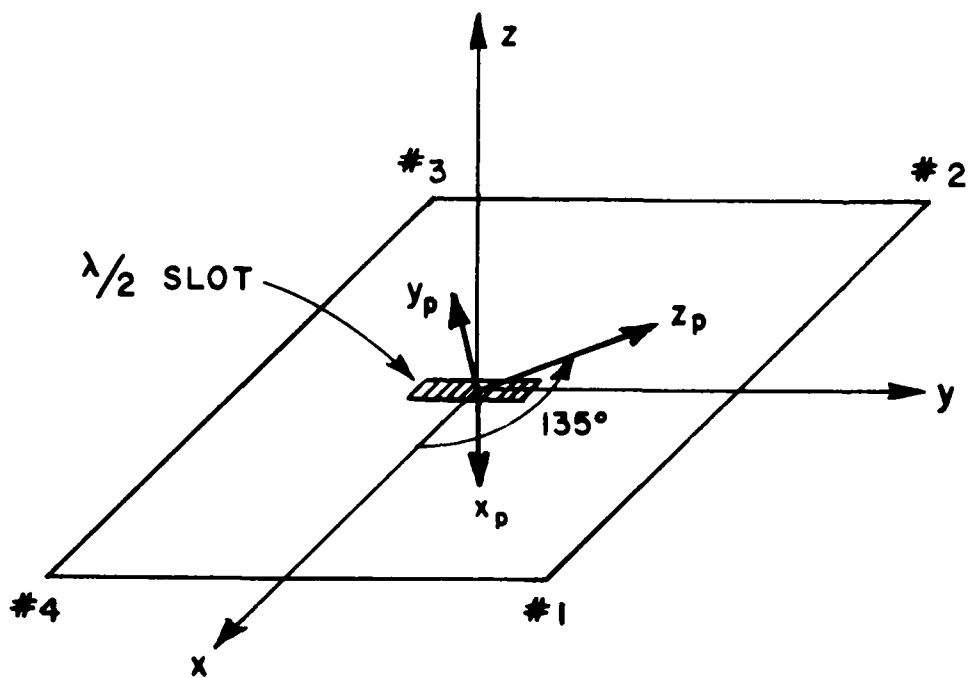


Figure 16. A $\lambda/2$ slot mounted on top of a square ground plane.

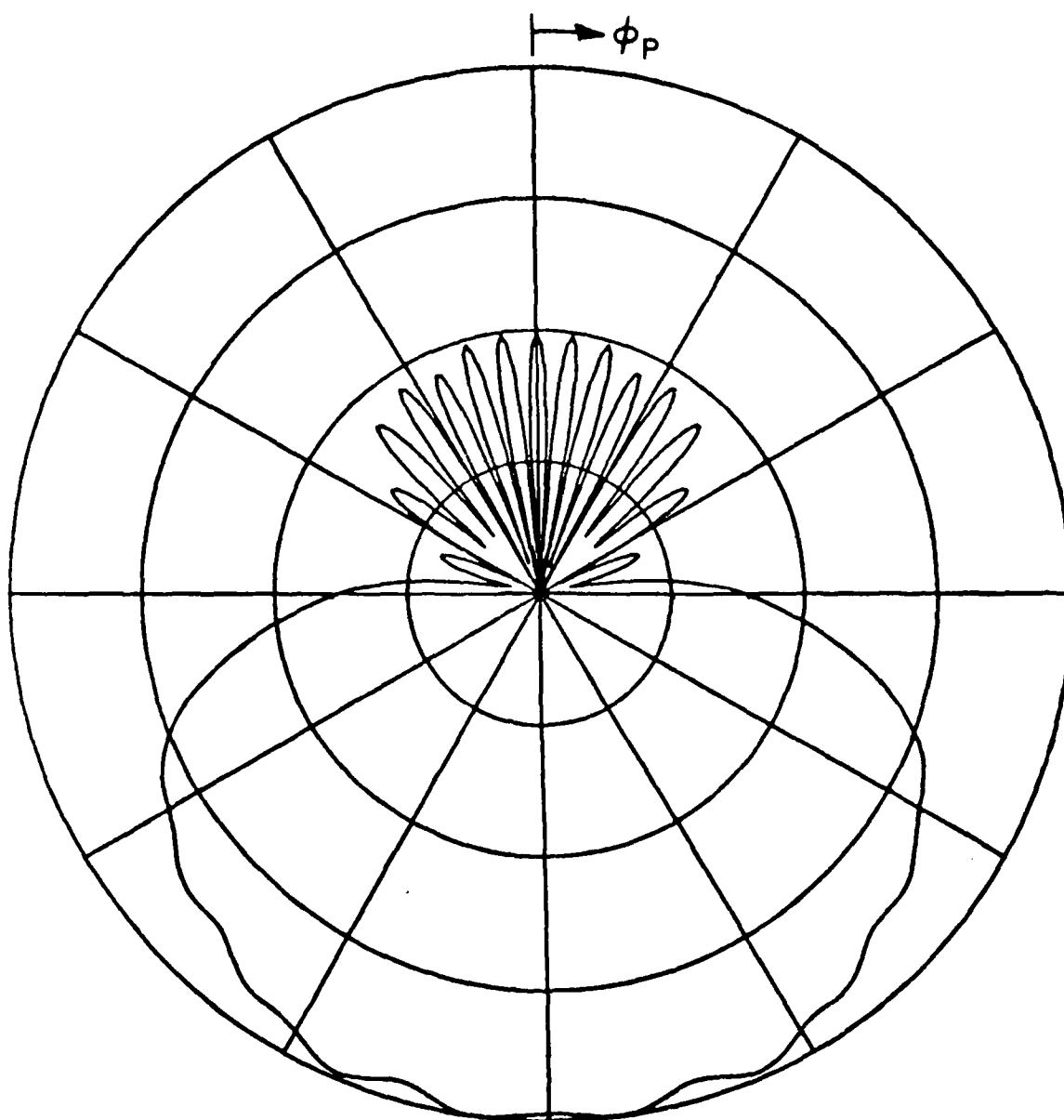


Figure 17a. $E_{\theta p}$ radiation pattern of $\lambda/2$ slot antenna mounted on a square ground plane at a frequency of 10 GHz.

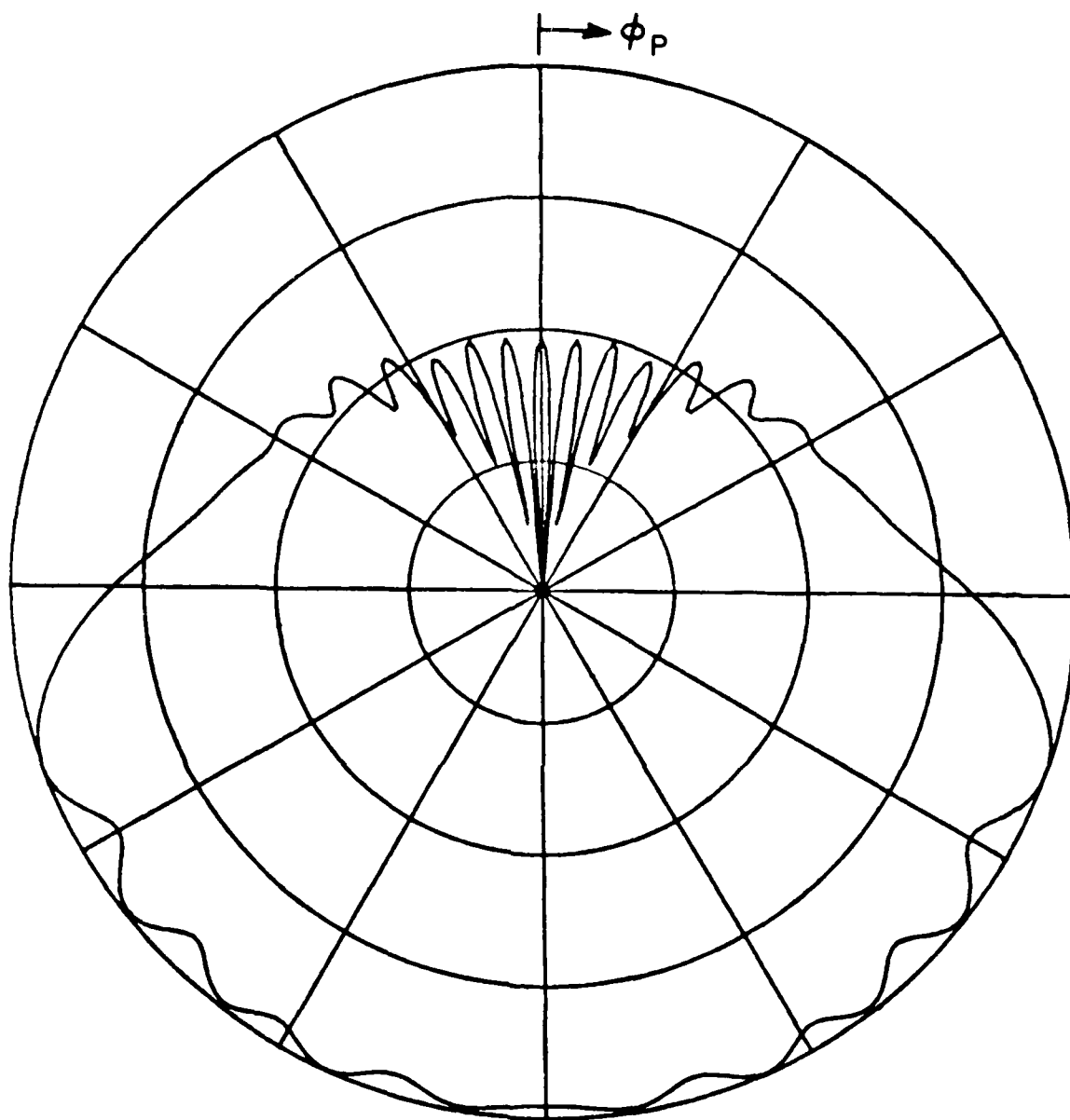


Figure 17b. $E_{\phi p}$ radiation pattern of $\lambda/2$ slot antenna mounted on a square ground plane at a frequency of 10 GHz.

8. Consider the pattern of a $\lambda/2$ electric dipole located near a rectangular box as shown in Figure 18. The input data is given by:

```

F,F,F
T,T
90.,135.,90.
0,360,1
4.
6
4,4,4,4,4,4
0.,0.,0.
6.,0.,0.
6.,6.,0.
0.,6.,0.
0.,6.,0.
6.,6.,0.
6.,6.,-6.
0.,6.,-6.
0.,0.,-6.
0.,6.,-6.
6.,6.,-6.
6.,0.,-6.
6.,0.,0.
0.,0.,0.
0.,0.,-6.
6.,0.,-6.
6.,6.,0.
6.,0.,0.
6.,0.,-6.
6.,6.,-6.
0.,0.,0.
0.,6.,0.
0.,6.,-6.
0.,0.,-6.
1,F
-1.575,-1.575,2.23
0.,5,90.,-45.
1.,0.

```

The $E_{\theta p}$ polar radiation pattern is plotted in Figure 19. Note that the $E_{\phi p}$ is of negligible value. This same pattern is plotted in rectangular form in Figure 20, where it is compared with a measured result.

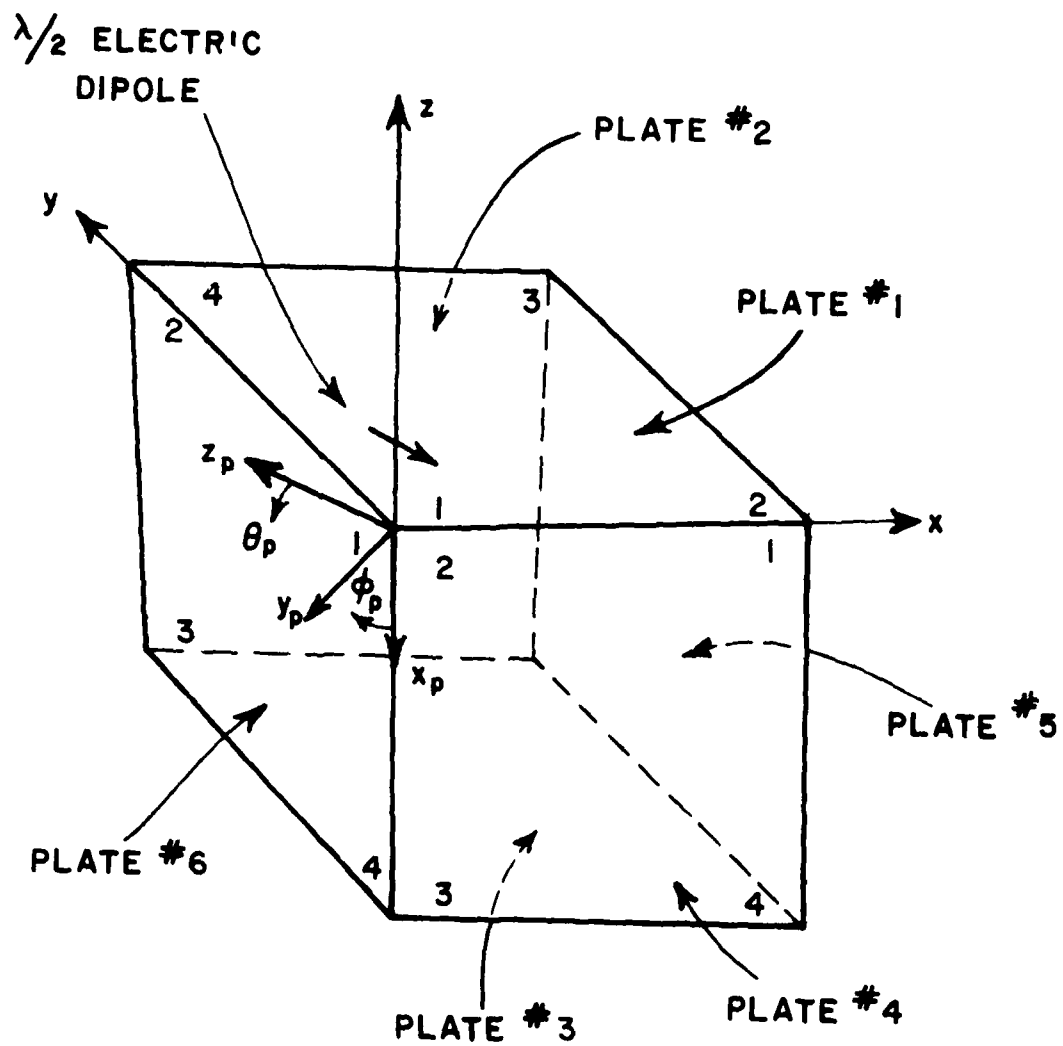


Figure 18. A $\lambda/2$ electric dipole in presence of a box structure.

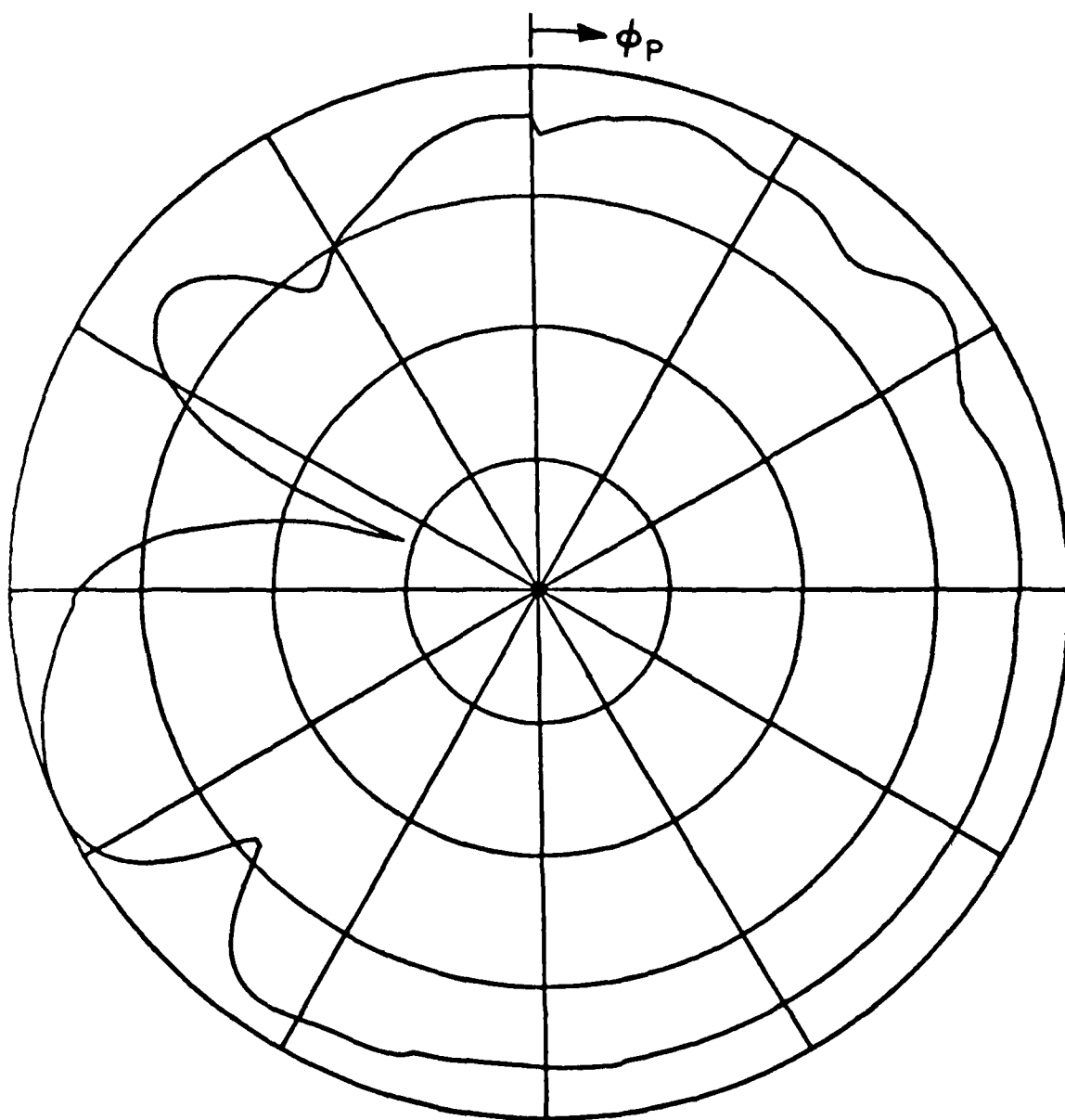


Figure 19. $E_{\theta p}$ radiation pattern for a $\lambda/2$ electric dipole in the presence of a rectangular box.

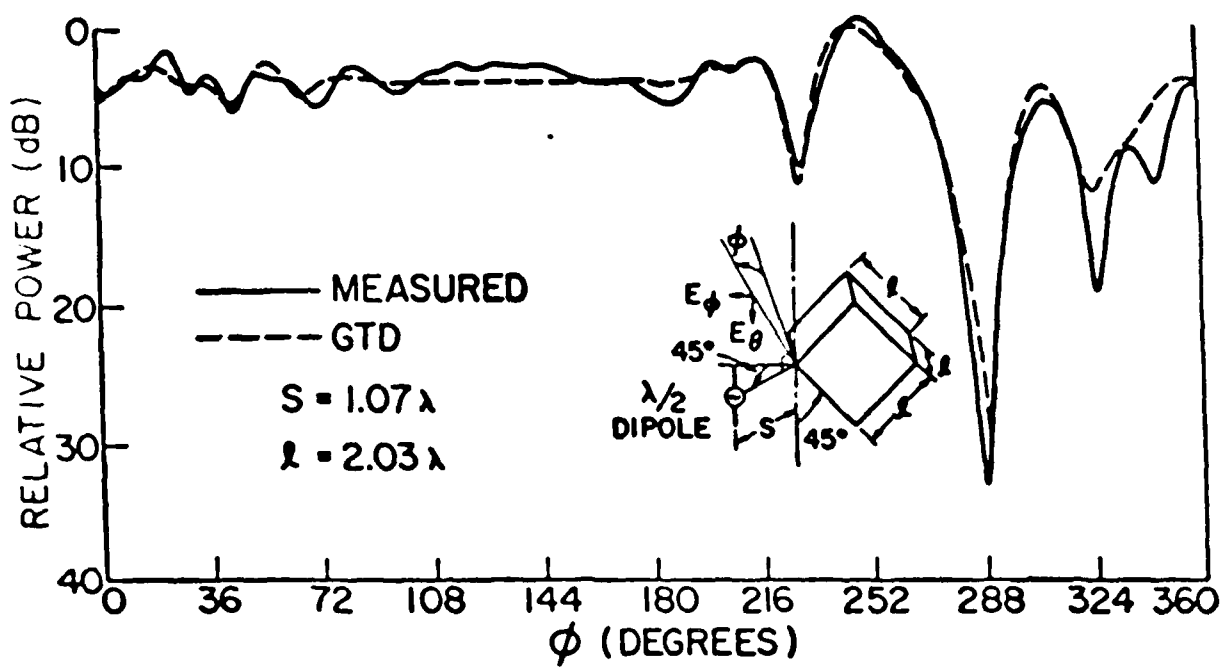


Figure 20. Comparison of measured and calculated $E_{\theta p}$ radiation pattern for a dipole near a box in the indicated plane.

9. Consider the various radiation patterns of an array of $\lambda/2$ electric dipoles situated $1/4\lambda$ above a square ground plane as shown in Figure 21.

a) Input data for 6 element array scanned at broadside:

```

F,F,F
T,T
-90.,0.,90.
0,360,1
10.
1
4
6.,6.,0.
-6.,6.,0.
-6.,-6.,0.
6.,-6.,0.
6,F
0.,-1.25,0.25
0,0.5,90.,0.
1.,0.
0.,-.75,.25
0.,.5,90.,0.
1.,0.
0.,-.25,.25
0.,.5,90.,0.
1.,0.
0.,.25,.25
0.,.5,90.,0.
1.,0.
0.,.75,.25
0.,.5,90.,0.
1.,0.
0.,1.25,.25
0,0.5,90.,0.
1.,0.

```

The $E_{\theta p}$ radiation pattern is plotted in Figure 22. Note that the ground plane has little effect for the broadside case.

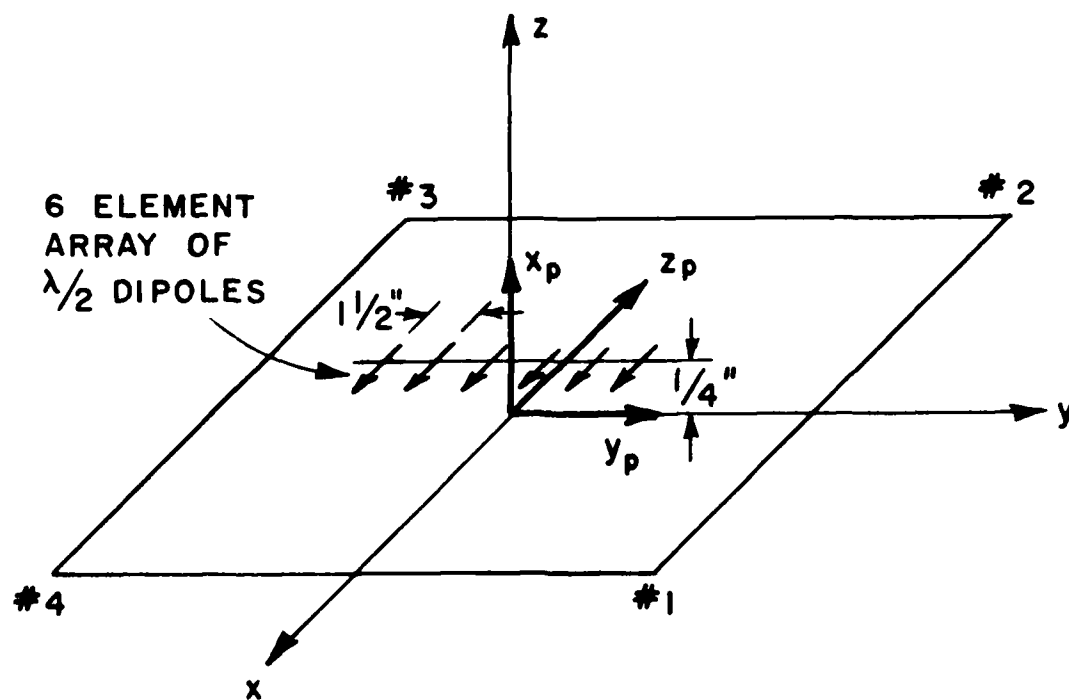


Figure 21. Six element $\lambda/2$ dipole array with uniform amplitude and phase scanned above a square ground plane.

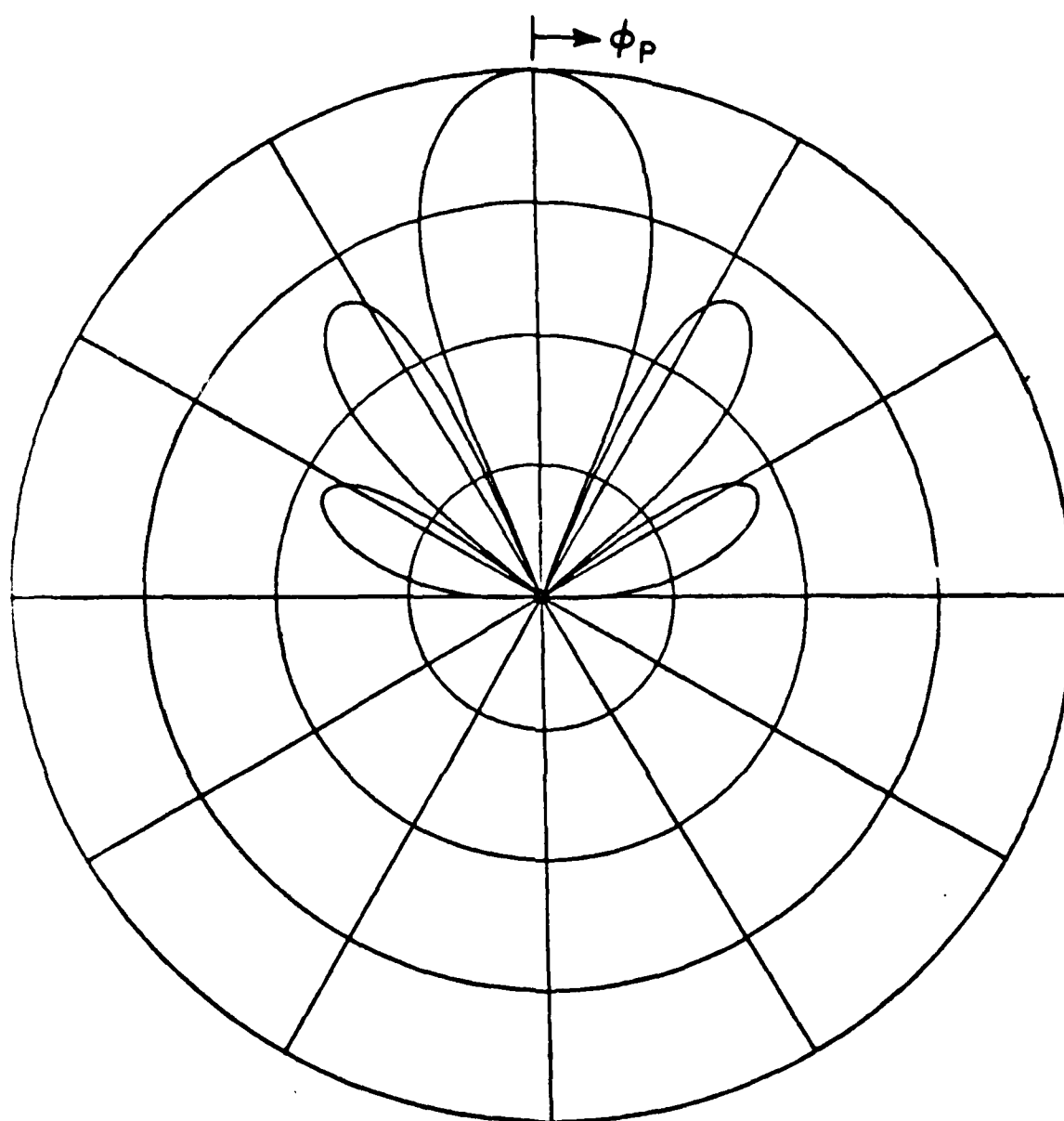


Figure 22. $E_{\theta p}$ radiation pattern for a six element array of $\lambda/2$ electric dipoles situated above a square ground plane scanned broadside at a frequency of 10 GHz.

b) Input data for 6 element array scanned $\sim 36^\circ$ from broadside:

```
F,F,F
T,T
-90.,0.,90.
0,360,1
10.
1
4
6.,6.,0.
-6.,6.,0.
-6.,-6.,0.
6.,-6.,0.
6,F
0.,-1.25,0.25
0,0.5,90.,0.
1.,225.
0.,-.75,.25
0,.5,90.,0.
1.,135.
0.,-.25,.25
0,.5,90.,0.
1.,45.
0.,.25,.25
0,.5,90.,0.
1.,-45.
0.,.75,.25
0,.5,90.,0.
1.,-135.
0.,1.25,.25
0,0.5,90.,0.
1.,-225.
```

The $E_{\theta p}$ radiation pattern is plotted in Figure 23.

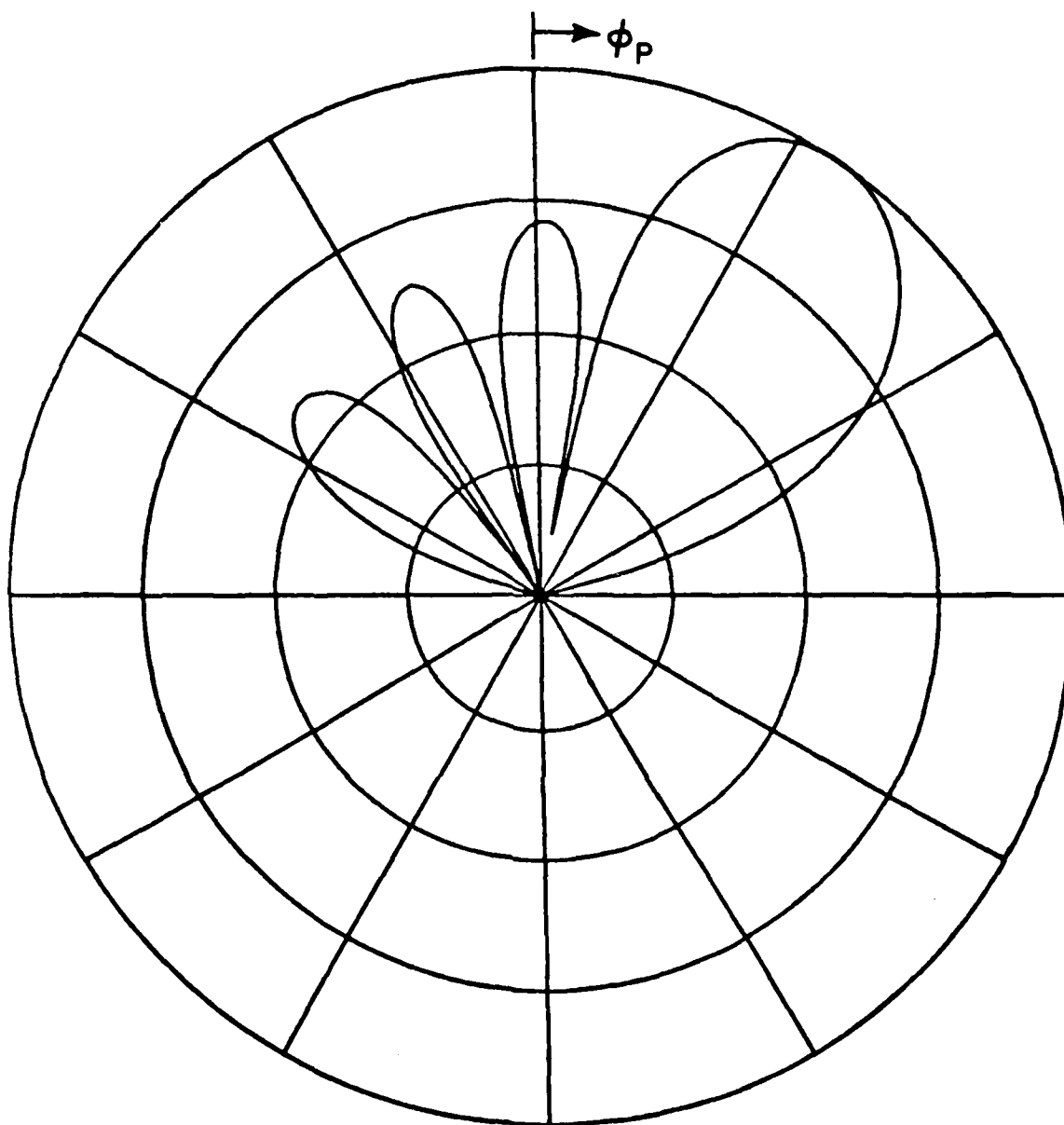


Figure 23. $E_{\theta p}$ radiation pattern for a six element array of $\lambda/2$ electric dipoles situated above a square ground plane scanned $\sim 36^\circ$ off broadside at a frequency of 10 GHz.

c) Input data for 6 element array scanned $\sim 72^\circ$ from broadside:

```
F,F,F
T,T
-90.,0.,90.
0,360,1
10.
1
4
6.,6.,0.
-6.,6.,0.
-6.,-6.,0.
6.,-6.,0.
6,F
0.,-1.25,0.25
0,0.5,90.,0.
1.,389.71
0.,-.75,.25
0.,5,90.,0.
1.,233.83
0.,-.25,.25
0.,5,90.,0.
1.,77.94
0.,.25,.25
0.,5,90.,0.
1.,-77.94
0.,.75,.25
0.,5,90.,0.
1.,-233.83
0.,1.25,.25
0,0.5,90.,0.
1.,-389.71
```

The $E_{\theta\rho}$ radiation pattern is plotted in Figure 24.

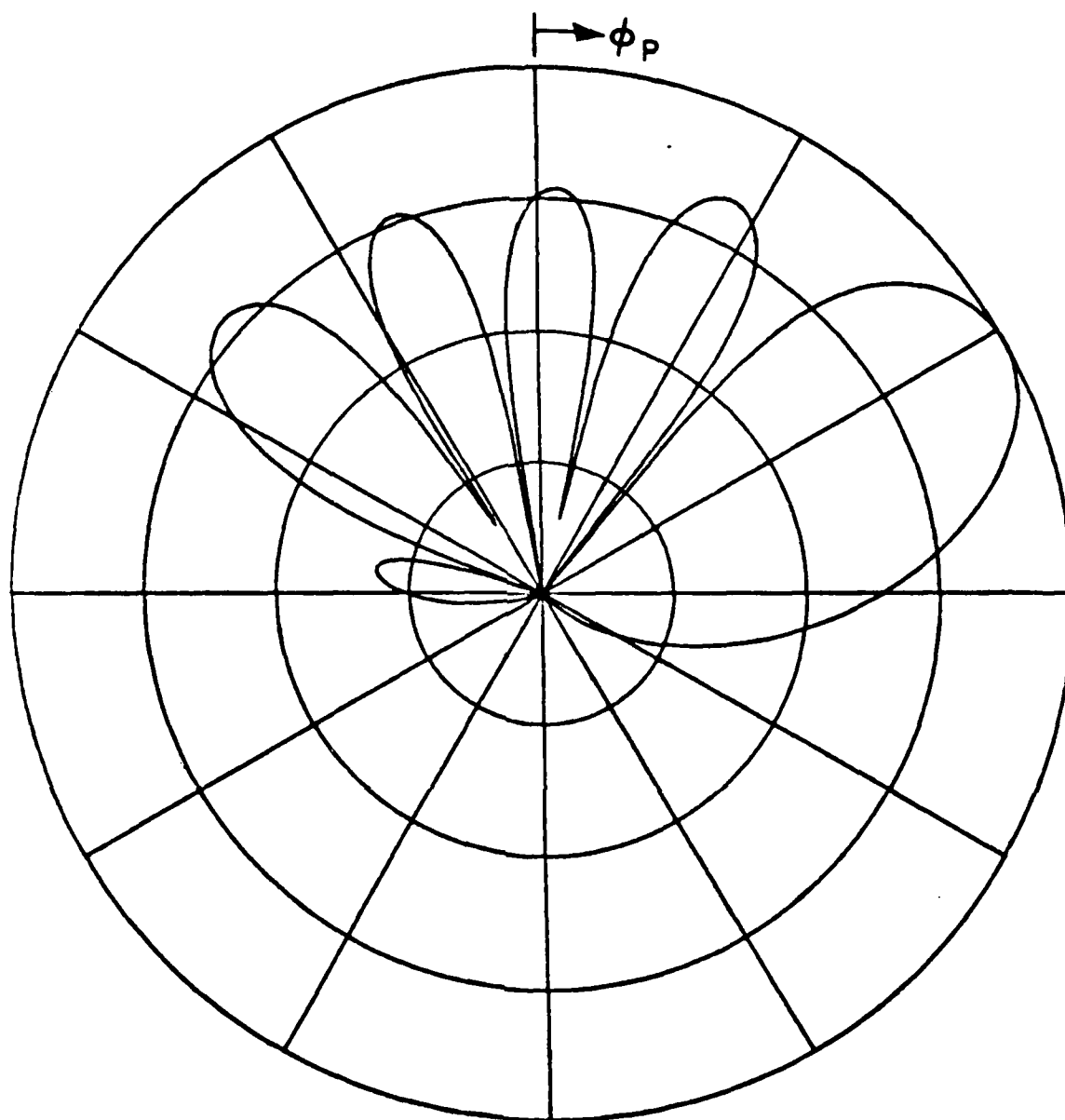


Figure 24. $E_{\theta p}$ radiation pattern for a six element array of $\lambda/2$ dipoles situated above a square ground plane and scanned at $\sim 72^\circ$ from broadside at a frequency of 10 GHz.

V. PROGRAM OUTPUT

The basic output from the computer code is a line printer listing of the results. Recall that the results of the program are the $E_{\theta p}$ and $E_{\phi p}$ radiation pattern values. In order to again describe these pattern components, let us consider the first few examples of the previous section. The computer code allows for a rotation of coordinates in terms of the pattern calculation. This is input in terms of the spherical angles THC, PHC. Using the geometry of examples #1 and #2 as given in Figure 3, $THC = PHC = 0^\circ$, such that the pattern coordinates are aligned with the structural coordinates. Thus, $E_{\theta p}$ would be the normal theta component of the field (i.e., $E_{\theta p} = \vec{E} \cdot \hat{\theta}_p = \vec{E} \cdot \hat{\theta}$, since $\hat{\theta}_p = \hat{\theta}$ in this case). Likewise, $E_{\phi p} = \vec{E} \cdot \hat{\phi}_p = \vec{E} \cdot \hat{\phi}$ in this case. Note that \vec{E} is the total radiated electric field.

Now let us suppose that one defines the same structure as above using the coordinate system shown in Figure 25. In order to take the same pattern cut as in the previous case, one must set $THC = 90^\circ$ and $PHC = 180^\circ$. Then with $THP = 90^\circ$, one will obtain the same pattern as given previously; however in this case, the pattern data will be inverted in terms of the plot as shown in Figure 26. Again, the radiation pattern is output in terms of $E_{\theta p}$ and $E_{\phi p}$ as given by

$$E_{\theta p} = \vec{E} \cdot \hat{\theta}_p$$

$$E_{\phi p} = \vec{E} \cdot \hat{\phi}_p$$

where θ_p and ϕ_p are the normal spherical angles in the x_p, y_p, z_p coordinate system.

In order to further understand this concept associated with the rotated pattern coordinates, the pattern coordinate system (x_p, y_p, z_p) is illustrated in each of the figures given in the previous example section.

In that one is not able to deliver standard plot routines from one computer system to another, our plot package is not included as an integral part of this computer code. However, a simple polar plot routine is given in Appendix I which can be used to duplicate the polar graphs given in the previous section. This plot routine is included as part of the code such that one must be mindful of its inclusion. It is possible that the program will not compile if a "PLOT" subroutine is not available.

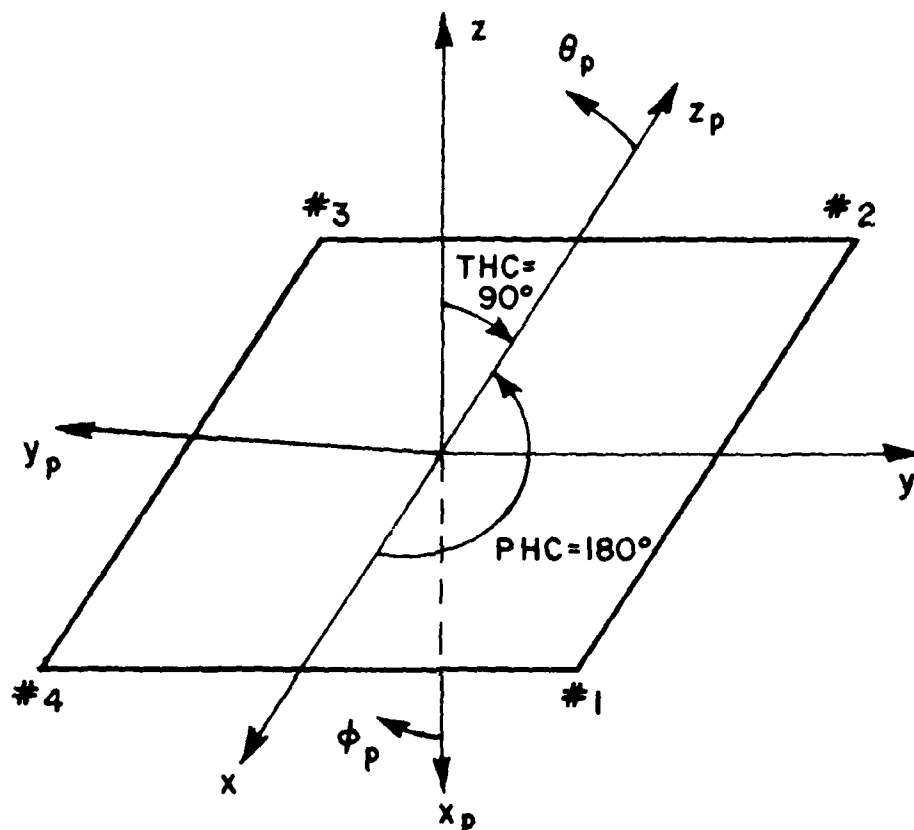


Figure 25. Example of the pattern coordinates using a different fixed coordinate system for the structure of Figure 3.

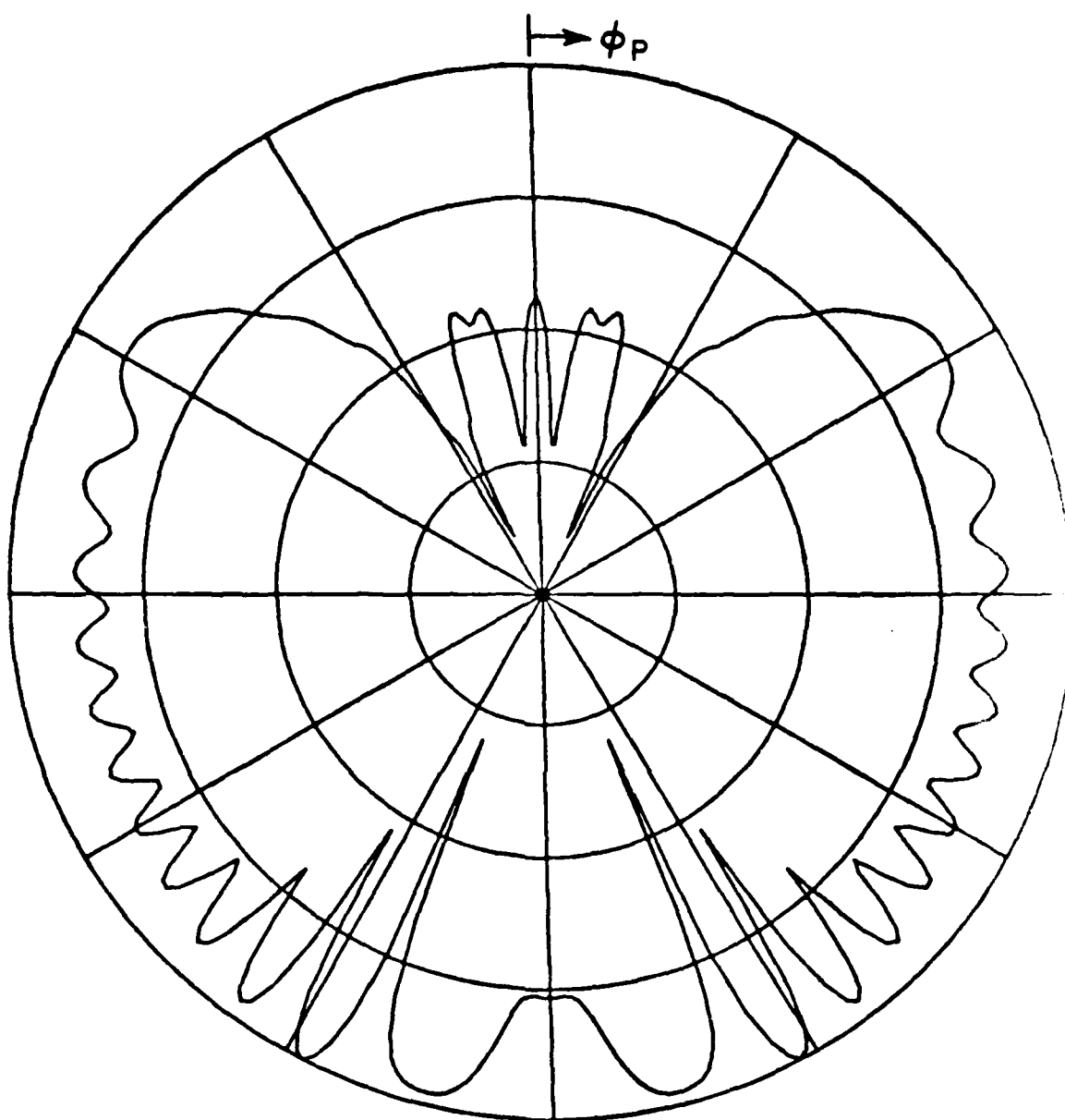


Figure 26. Illustration of inverted pattern obtained using geometry of Figure 25.

APPENDIX I

The following is a listing of a polar plot subroutine which can be used to generate the polar patterns given in Section IV. Note that this code refers to two subroutines "PLOTS" and "PLOT" which must be added by the system or operator. The definitions of these routines are given in the comments associated with the code.

```

SUBROUTINE POLPLT(ET,RP,IPLT,IPHS,IDM)
C!!!!
C!!!! THIS ROUTINE IS USED TO PLOT THE RESULTS IN TERMS OF A
C!!!! POLAR PLOT. THE CALL TO SUBROUTINE "PLOTS" IS USED TO INITIALIZE
C!!!! THE PLOTTER. THE CALLS TO THE SUBROUTINE "PLOT" ARE USED TO
C!!!! DRAW THE DATA AS FOLLOWS:
C!!!!
C!!!!     CALL PLOT(X,Y,N)
C!!!!
C!!!!     X,Y=COORDINATES OF THE NEW PLOT POINT.
C!!!!
C!!!!     N=2     PEN IS DOWN MOVING TO THE NEW POINT.
C!!!!     N=3     PEN IS UP MOVING TO THE NEW POINT.
C!!!!     N=999   BUFFER USED TO STORE PLOT DATA IS EMPTIED TO PLOTTER
C!!!!
C!!!!     N<0     IMPLIES ORIGIN SHIFT TO THE NEW POINT.
C!!!!     N>0     IMPLIES NO ORIGIN SHIFT AFTER MOVING TO NEW POINT.
C!!!!
COMPLEX ET(IDM)
DIMENSION IPHF(100)
DATA PI,TPI,DPR/3.14159265,6.2831853,57.29577958/
EMX=0.
DO 101 IP=0,360,IPHS
I=IP+1
EM=CABS(ET(I))
IF(EM.GT.EMX) EMX=EM
101 CONTINUE
CALL PLOTS(IPHF,100,3)
CALL PLOT(4.25,5.5,-3)
C *** POLAR GRID ***
DO 110 I=1,4
RG=RP*I/4.
CALL PLOT(RG,0.,3)
DO 110 J=0,360,2
ANG=J/DPR
XX=RG*COS(ANG)
YY=RG*SIN(ANG)
110 CALL PLOT(XX,YY,2)
DO 112 I=1,6

```



```

ANG=(I-1)*PI/6.
ANGS=ANG+PI
ANGF=ANG
IF(I.EQ.2*(I/2)) GO TO 111
ANGS=ANG
ANGF=ANG+PI
111 CONTINUE
XX=RP*COS(ANGS)
YY=RP*SIN(ANGS)
CALL PLOT(XX,YY,3)
XX=RP*COS(ANGF)
YY=RP*SIN(ANGF)
112 CALL PLOT(XX,YY,2)
C *** PATTERN PLOT ***
DO 120 IP=0,360,IPHS
I=IP+1
ETM=CABS(ET(I))/FMX
IF(IPLT-2) 121,122,123
121 RD=RP*ETM
GO TO 125
122 RD=RP*ETM*ETM
GO TO 125
123 IF(ETM.LT.0.01) ETM=0.01
RD=20.*ALOG10(ETM)
IF(RD.LT.-40.) RD=-40.
RD=RP*(RD+40.)/40.
125 CONTINUE
ANG=IP/FPB
XX=RP*SIN(ANG)
YY=RP*COS(ANG)
IPEN=2
IF(I.EQ.1) IPEN=3
120 CALL PLOT(XX,YY,IPEN)
CALL PLOT(4.25,-5.5,-3)
130 CONTINUE
CALL PLOT(0.,0.,999)
RETURN
END

```

END

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